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Original Article

# An Update to the Malthus Model for Radiotherapy Utilisation in England

S. Heritage [*1], S. Sundaram [*1], N.F. Kirkby [†‡], K.J. Kirkby [†‡], T. Mee [†‡], R. Jena [§]

[*] School of Clinical Medicine, University of Cambridge, Cambridge, UK
[†] Division of Cancer Sciences, School of Medical Sciences, Faculty of Biology, Medicine and Health, University of Manchester, Manchester, UK
[‡] The Christie NHS Foundation Trust, Manchester Academic Health Science Centre, Manchester, UK
[§] Department of Oncology, University of Cambridge, Cambridge, UK

## Abstract

*Aims:* The Malthus Programme predicts national and local radiotherapy demand by combining cancer incidence data with decision trees detailing the indications, and appropriate dose fractionation, for radiotherapy. Since the last model update in 2017, technological advancements and the COVID-19 pandemic have led to increasing hypofractionation of radiotherapy schedules. Indications for radiotherapy have also evolved, particularly in the context of oligometastatic disease. Here we present a brief update on the model for 2021. We have updated the decision trees for breast, prostate, lung and head and neck cancers, and incorporated recent cancer incidence data into our model, generating a current estimate of fraction demand for these four cancer sites across England.

*Materials and methods:* The decision tree update was based on evidence from practice-changing randomised controlled trials, published guidelines, audit data and expert opinion. Site- and stage-specific incidence data were taken from the National Disease Registration Service. We used the updated model to estimate the proportion of patients who would receive radiotherapy (appropriate rate of radiotherapy) and the fraction demand per million population at a national and Clinical Commissioning Group level in 2021.

*Results:* The total predicted fraction demand has decreased by 11.4% across all four cancer sites in our new model, compared with the 2017 version. This reduction can be explained primarily by greater use of hypofractionated treatments (including stereotactic ablative radiotherapy) and a shift towards earlier stage presentation. The only large change in appropriate rate of radiotherapy was an absolute decrease of 3% for lung cancer.

*Conclusions:* Compared with our previous model, the current version predicts a reduction in fraction demand across England. This is driven principally by hypofractionation of radiotherapy regimens, using technology that requires increasingly complex planning. Treatment complexity and local service factors need to be taken into account when translating fraction burden into linear accelerator demand or throughput.



*Keywords:* Breast cancer; head and neck cancer; health service needs and demands; lung cancer; prostate cancer; radiotherapy

## Introduction

The Malthus model is a radiotherapy demand simulation for England, which was originally developed in 2011 to provide predictions for external beam radiotherapy treatment in adults if all patients were treated to the highest level of clinical evidence [1]. At the request of the National Radiotherapy Advisory Group, the model was developed into a freely distributable tool to facilitate discussion between providers and commissioners for radiotherapy services in England [2]. Since the dissolution of the National Radiotherapy Advisory Group, Malthus has been maintained as a research tool and used for scenario planning of specialised services, such as magnetic resonance linear accelerator and proton beam therapy [3–6]. The clinical evidence behind the model was updated in 2016. In the past 5 years, we have seen significant changes in clinical practice, with trends towards the use of hypofractionation in curative radiotherapy treatment, and in oligometastatic disease. The impact of new evidence around hypofractionation has been particularly relevant as part of the response to reduced capacity for radiotherapy delivery during the early stages of the COVID-19 pandemic. Here we present a brief update on the model for 2021, focusing on changes to

Author for correspondence: R. Jena.
*E-mail address:* rjena@nhs.net (R. Jena).
[1] Joint first authors.

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the clinical evidence for four main tumour types, namely breast, prostate, head and neck, and non-small cell lung cancer (NSCLC). We provide a concise review of the clinical evidence used in the updated model and present simulations for evidence-based radiotherapy demand evaluating clinical scenarios.

## Materials and Methods

### *Model Update and Evidence Synthesis*

The structure of the model has been previously described [1,2]. In brief, population-specific cancer incidence rates are used to create a cohort of virtual patients who represent the cancer burden of a region. The virtual patients are fed into clinical decision trees for each of 21 key tumour types. Based on disease stage, concomitant treatment and clinical factors, the decision trees encode appropriate utilisation of radiotherapy for each patient. The radiotherapy demand is summed over all virtual patients to produce population-level predictions for radiotherapy demand in treatment fractions. Since the last update, the model code has been further updated to allow for more sophisticated simulations, including the use of specific radiotherapy treatment platforms such as stereotactic ablative body radiotherapy (SABR), magnetic resonance linear accelerator and proton beam therapy, and an additional capability to simulate waiting-time pathways has been added. The last version of the model was published in 2017 and we use this version as a baseline for comparison in the analysis presented here [3].

Curation of the clinical evidence base for radiotherapy was carried out by a review of key randomised clinical trials published in the past 5 years, as well as discussion with key opinion leaders in each of the tumour types. In view of the trend towards hypofractionation, simulations have been carried out anticipating the implications of key hypofractionation studies that have yet to report. Full documentation on the clinical decision trees is available online [7].

### *Evidence Review — Breast Cancer*

Following the last decision tree update, 40 Gy and 15 fractions became the standard of care for adjuvant breast radiotherapy following the START-B trial's demonstration of equivalent oncological efficacy and fewer late effects than the widely utilised 50 Gy/25 fractions regimen [8].

The IMPORT (Intensity Modulated and Partial Organ Radiotherapy) LOW trial showed that partial breast irradiation has equivalent local relapse rates and equivalent or fewer late normal tissue adverse effects [9]. In the IMPORT HIGH trial, participants were randomised to two treatment arms, receiving varying doses of radiotherapy across the breast with a concomitant boost dose to the tumour bed, whereas patients in the control arm received standard radiotherapy [10]. The 10-year follow-up results are yet to be fully reported, but if the results show non-inferiority then it may indicate that simultaneous integrated boost should be given as 15 fractions [10]. Similar rates of moderate/marked adverse effects at 3 years were reported between simultaneous integrated boost intensity modulated radiotherapy (IMRT) and whole-breast plus sequential boost IMRT delivered over 3 and 4.5 weeks, respectively [11]. According to recent Royal College of Radiologists guidelines, hypofractionated boost doses equivalent to 16 Gy/8 fractions are acceptable [12,13].

Early in 2020, the 10-year outcomes of the FAST study were published [14]. This showed that 28.5 Gy in five once-weekly fractions was comparable with 50 Gy/25 fractions/5 weeks, and that there was no significant difference in normal tissue effects [14]. The recently published FAST-Forward trial then showed that 26 Gy/5 fractions over 1 week could be used in whole-breast, chest wall and partial breast radiotherapy and was deemed non-inferior to the international standard of 15 fractions up to 5 years [15]. The five-fraction regimen is thought to be suitable for women with ductal carcinoma *in situ* or early-stage invasive breast carcinoma, although caution is recommended when used in patients with nodal disease, pending the publication of the FAST-Forward nodal sub-study [16].

Implementation of 26–28.5 Gy/5 fractions schedules into clinical practice was considerably accelerated by the COVID-19 pandemic, and is now routinely used for most women receiving adjuvant breast cancer radiotherapy [16–19].

### *Evidence Review — Prostate Cancer*

In recent years, active surveillance has become the dominant initial treatment method for low-risk prostate cancer patients. The ProtecT trial, key in instrumenting this change, showed no significant overall survival difference between men treated with initial radiotherapy, surgery or active surveillance in this risk category [20]. Although this drastically reduces the number of men receiving up-front radiotherapy, many of these patients will move from active surveillance to definitive treatment over time. We have used the figures from the ProtecT study to model this crossover, although this may not reflect the outcomes of more modern active surveillance programmes.

As observed in other disease sites, radiotherapy schedules for localised prostate cancer are becoming increasingly hypofractionated. The now standard 60 Gy/20 fractions regimen was shown to be non-inferior to the previously used schedule of 74 Gy/37 fractions in a number of trials, including CHHIP [21]. This important change in radiotherapy practice had already been added to our decision tree in 2017.

Meanwhile, the ongoing PACE-B trial is comparing conventional/moderately hypofractionated radiotherapy to a SABR regimen of 36.25 Gy/5 fractions/1–2 weeks for low- and lower–intermediate-risk cancers (i.e. excluding Gleason 3 + 4) [22]. The acute toxicity results have been favourable, but 5-year oncological outcomes are not due for publication until 2023 [22]. Nevertheless, confidence in the efficacy of this SABR regimen was such that some centres used it during the coronavirus pandemic. There is also considerable interest in

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extending such 'ultrahypofractionated' radiotherapy schedules to higher–intermediate- and high-risk cancers, and the PACE-C trial is currently investigating the same five-fraction regimen in this group. We consider it likely that SABR will replace the 20-fraction regimen for most low- and lower–intermediate-risk cancers in the near future. However, there is less certainty of the same for higher-risk patients. The HYPO trial showed that a 42.7 Gy/7 fractions schedule was non-inferior to the previously standard 74 Gy/37 fractions regimen in an intermediate–high-risk cohort, but the predominant use of three-dimensional conformal radiotherapy techniques coupled with lack of neoadjuvant androgen deprivation therapy means that the results cannot necessarily be extrapolated to current UK practice [23]. Furthermore, the tight margins needed for safe delivery of SABR may make it difficult to reliably encompass areas of locally advanced tumour, which could then go on to seed micrometastases.

Radical treatment for patients with low-burden oligometastatic disease is now also included in the model. The STAMPEDE trial demonstrated a benefit in failure-free survival for adding radiotherapy compared with systemic therapy alone, for men presenting with metastatic prostate cancer with a low metastatic burden (i.e. fewer than four bony metastases and no visceral metastases) [24]. Two alternative fractionation schedules were used for the intervention group in this trial (55 Gy/20 fractions/4 weeks and 36 Gy/6 fractions/6 weeks) and both are being used in clinical practice now, with the latter technique making radical treatment for oligometastatic disease more accessible to frail prostate cancer patients.

*Evidence Review – Non-small Cell Lung Cancer*

The gold-standard treatment for patients with stage I–IIIA NSCLC and an adequate performance status is surgery, but resection rates have historically been low in the UK due to a number of logistical factors. Since the inception of the National Lung Cancer Audit, which aims to remove some of these barriers, the proportion of operable patients with stage I–IIIA disease receiving surgery has steadily been increasing [25].

SABR is already the standard of care for inoperable early-stage NSCLC. This follows mainly from the CHISEL trial, which showed better oncological outcomes for SABR schedules of 54 Gy/3 fractions or 48 Gy/4 fractions (for tumours close to the chest wall), compared with conventional or moderately hypofractionated regimens of 60–66 Gy/30–33 fractions and 55 Gy/20 fractions [26].

However, three-fraction SABR regimens have been associated with significant treatment-related mortality when delivered to 'central' tumours, located within 2 cm of the proximal bronchial tree (PBT) or brachial plexus, due to toxicity to thoracic organs at risk [27]. The SABR Consortium guidelines recommend a cautious fractionation schedule of 60 Gy/8 fractions for patients whose tumours lie 1–2 cm from the PBT, whereas American guidelines advise a 50 Gy/4–5 fractions schedule [28]. In practice, SABR is used cautiously for early-stage NSCLC in the UK, with a five-fraction regimen being used predominantly for peripheral tumours. Some central tumours can be treated with eight-fraction SABR, but 'ultracentral' tumours (<1 cm from the PBT) continue to be treated exclusively by moderately hypofractionated, conventional or accelerated regimens. We have replicated this hitherto cautious introduction of SABR into clinical practice in our modelling.

In patients presenting with metastatic NSCLC, the brain is often the first site of metastasis. Those whose intracranial disease would be amenable to stereotactic radiosurgery alone, i.e. with a total volume <20 cm3 of cerebral metastases in one to four separate sites, according to Royal College of Radiologists guidelines, can present with treatable thoracic disease and a good performance status [13]. These patients can be considered for a combination of systemic therapy and local radiotherapy to the chest and brain [29].

*Evidence Review – Head and Neck Cancer*

IMRT is the accepted radiotherapy method for patients undergoing primary and adjuvant head and neck squamous cell carcinoma (HNSCC) treatment, except in T1/2 N0 glottic cancer and for low-dose palliative radiotherapy [13].

A recent meta-analysis of HNSCC radiotherapy showed that altered fractionation can improve overall and progression-free survival compared with conventional radiotherapy, the greatest benefit seen in hyperfractionated radiotherapy [30].

A further meta-analysis found that accelerated radiotherapy does not result in a significant improvement in locoregional control or overall survival in high-risk patients and that accelerated radiotherapy resulted in more frequent acute toxicity [31].

The other radiotherapy recommendations remain largely unchanged, as per the most recent Royal College of Radiologists guidelines [13]. Palliative radiotherapy dose fractionation regimens for locally advanced non-metastatic head and neck cancer remain very variable, in contrast to the well-standardised regimens of curative radiotherapy for locally advanced head and neck cancer [32].

During the COVID-19 pandemic, a local study proposed that hypofractionated radiotherapy should be considered in place of concurrent chemoradiotherapy for human papillomavirus-positive T1-T3N0–N2c HNSCCs, human papillomavirus-negative T1-T2N0 HNSCCs and select stage III HNSCCs in patients suitable for hypofractionated radiotherapy [33]. However, most UK centres have now returned to usual pre-pandemic clinical practice, making this of minimal clinical significance.

*Alternative Treatment Scenarios*

There are several key areas identified in the evidence review where practice will probably change soon. We have incorporated some of these potential changes into additional versions of our model, in order to speculate on how future updates in radiotherapy practice might impact fraction demand.

One such simulation models the potential implications of both PACE-B and -C showing non-inferiority of SABR in low–intermediate- and intermediate–high-risk prostate

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cancers. This simulation incorporates five-fraction SABR for almost all localised or locally advanced disease, except for high-risk tumours that require particularly complex plans and/or nodal irradiation, and would therefore probably be treated with 20 fractions even if PACE-C showed non-inferiority of SABR in a high-risk cohort [22].

Another simulation is the inclusion and exclusion of five fractions in the breast cancer model, taking into consideration the recent publication of the FAST-Forward trial [15].

## Results

Table 1 shows a nationwide overview of the current model output for four disease sites. The appropriate rate of radiotherapy (ARR) utilisation represents the proportion of cancer patients for whom radiotherapy is indicated. Historically, ARR has been used as the output of radiotherapy utilisation models. The fraction burden is calculated as a highly discriminant factor for all aspects of radiotherapy capacity and can give a better prediction of demand placed on radiotherapy departments based on modern evidence-based fractionation. To reflect variations in cancer burden between the different Clinical Commissioning Groups (CCG), the fraction burdens for the CCG with the lowest and highest disease-specific cancer burden are also shown. In each case, comparisons of ARR and fraction burden are provided with the 2017 model as a baseline. The full model simulations for all 211 CCGs are available online [7].

Part of the shift in simulated fraction burden relates to an update of the disease-specific stage distribution that is currently available from the cancer registry [34]. The stage distribution at national level is illustrated in Table 2. A shift to earlier stage disease at presentation was observed in all four disease sites, and the total predicted fraction burden has decreased by 11.7%.

## Discussion

### *Overview of the Model Results*

The simulations generated by the updated Malthus model illustrate a trend that has been observed within sequential model updates. Simulations have shown an increase in predicted demand for radiotherapy (i.e. the number of patients receiving any radiotherapy in the non-palliative setting) as the cancer burden increases and more patients are treated with non-palliative intent. However, the impact on radiotherapy treatment fraction burden has been counterbalanced by trends towards shorter fractionation regimens. Improvements in radiotherapy technology have driven the trend towards hypofractionation, but the reduction in absolute numbers of treatment fractions delivered in general purpose linear accelerators comes at the expense of increased treatment complexity. This influences the demands on staff and highly specialised treatment platforms that are not adequately appreciated in a model that

**Table 1**
The appropriate rate of radiotherapy (ARR), total number of fractions and fractions per million simulated for England for the four cancer sites with updated evidence. Two scenarios of fully implemented clinical trial results are also simulated for breast and prostate. The lowest and highest Clinical Commissioning Group (CCG) simulated fractions per million are given to show the local-level range within England

| Cancer site | Scenario | England | | | CCG-level fractions per million | |
|---|---|---|---|---|---|---|
| | | ARR | Fractions | Fractions per million | Minimum | Maximum |
| Lung | Original | 61% | 305 962 | 5909 | 2522 | 12 154 |
| | Updated | 58% | 257 173 | 4515 | 2105 | 9989 |
| Breast | Original | 75% | 736 924 | 12 156 | 3688 | 17 429 |
| | Updated | 74% | 676 246 | 11 872 | 3583 | 16 988 |
| | Updated including Fast-Forward | 74% | 453 014 | 7953 | 2410 | 11 461 |
| Prostate | Original | 51% | 408 740 | 7175 | 1706 | 14 665 |
| | Updated | 52% | 364 053 | 6391 | 1543 | 14 349 |
| | Updated including PACE | 52% | 240 078 | 4214 | 1165 | 9273 |
| Head and neck | Original | 81% | 285 739 | 5016 | 2538 | 9619 |
| | Updated | 81% | 236 565 | 4153 | 2102 | 7949 |
| Total across all four sites | Original | NC | 1 737 365 | 30 256 | 10 454 | 53 867 |
| | Updated | NC | 1 534 037 | 27 038 | 9333 | 49 275 |
| | Updated including Fast-Forward + PACE | NC | 1 186 830 | 20 907 | 7782 | 38 672 |
| | % difference (original versus updated) | - | -11.7% | -11.0% | -10.7% | -8.5% |
| | % difference (original versus updated including Fast-Forward + PACE | - | -31.7% | -31.1% | -25.6% | -28.2% |

NC, not calculated.

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**Table 2**
Updated stage presentation data for England, used for the new England appropriate rate of radiotherapy simulation [34]

| Cancer site | Year | Stage I | Stage II | Stage III | Stage IV |
|---|---|---|---|---|---|
| Lung | 2013–2015 | 17% | 8% | 21% | 54% |
| Lung updated | 2016–2018 | 21% | 8% | 21% | 50% |
| Breast | 2013–2015 | 44% | 40% | 10% | 6% |
| Breast updated | 2016–2018 | 45% | 41% | 9% | 5% |
| Prostate | 2013–2015 | 35% | 23% | 21% | 21% |
| Prostate updated | 2016–2018 | 36% | 17% | 25% | 21% |

considers radiotherapy utilisation rates on its own. Therefore, the calculation of the number of linear accelerators required to service the simulated number of fractions should be undertaken in each radiotherapy department where local-level factors can be taken into account.

One motivation for the 2021 model update was to better understand the ongoing trend towards hypofractionation in the context of the COVID-19 pandemic. As has been observed with many of the healthcare innovations that were created through preparation for the pandemic, clinical experience of the safety and utility of such regimens, together with timely release of clinical evidence, has resulted in a permanent change in practice that we have encoded in the model update [17–19].

Finally, the simulations presented in this model update are run for the whole of England, for brevity. The model was always designed to produce simulations that reflected local variations in cancer burden and treatment practice, but cannot fully encapsulate patient choice at the local level. Trends identified in the model simulations will have more critical effects in some parts of the country than others. Simulation outputs for each CCG are available in the online repository. The results presented are for 2021 only, to highlight the difference between the previous and the updated evidence base. There are different factors that could change the demand for radiotherapy over time, such as changing local demographics and local incidence levels. Demographic factors, such as regional migration and age structure, will cause the changes in an inner-city region to be different to a rural retirement region. Equally, the incidence rates of different cancers are changing at different rates and therefore the local cancer profile will also determine the overall rate that incidences are changing within that region [35]. Overall, the trend of incidence rates of cancer is to increase yearly. The Malthus model has both incidence projection and population projection models built in and takes these into account when running simulations that cover multiple years [35,36].

## Observations and Conclusions for Specific Tumour Sites

*Breast Cancer*

In comparison with the 2017 model, the update shows the ARR for breast cancer has reduced by 1%, regardless of inclusion of the FAST-Forward study results. Breast cancer already has a well-established screening process in place that aims to detect early-stage disease, meaning that there has been minimal change in stage distribution. Furthermore, there is an established evidence base for radiotherapy indications [13,37]. Together, these may explain the lack of change in ARR.

The fractions per million in England have reduced by 284 in comparison with the 2017 model and by 4203 fractions per million if the Fast-Forward trial results of five fractions are included. This highlights the impact that implementation of the Fast-Forward trial protocol, which has been accelerated by the COVID-19 pandemic, may have on present and future fraction demand.

Hypofractionated regimens give the possibility for radiotherapy to be more accessible, for example through reducing travel burden and treatment duration for patients with multiple co-morbidities [18,19]. Hypofractionated radiotherapy can improve patient convenience and overcome delays in radiotherapy administration due to limited healthcare resources [38]. Although the current update does not reflect a change in the ARR, it would be important to repeat the analysis in the future to see if the recent FAST-Forward trial and IMPORT HIGH publications impact the future radiotherapy utilisation rate and to compare it with the model ARR.

*Prostate Cancer*

The proportion of men undergoing active surveillance for low-risk prostate cancer (instead of up-front 20-fraction radiotherapy) has increased from 25% in the previous decision tree to 90% in the current model. However, men with low-burden oligometastatic disease are now modelled to receive radical radiotherapy, whereas in the previous decision tree they would have been treated palliatively. Half of these men now receive 20 fractions for this indication, whereas the other half receive six fractions. Overall, there is little change in ARR for prostate cancer (an increase of 1%), suggesting that, in our model, the number of men now not receiving radiotherapy for low-risk disease (due to increased active surveillance) is about equal to the number who would now receive radical treatment for low-burden oligometastatic cancer. However, as some of the men in the latter group receive only six fractions rather than 20 fractions, there is still overall a relative decrease in fraction burden of almost 10%.

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Unsurprisingly, our speculative simulation of five-fraction SABR implementation for all low- and intermediate-risk prostate cancers, as well as some high-risk cancers, predicts a further relative decrease in fraction burden of over 34%. As described previously, although PACE-B is expected to show non-inferiority of SABR for low- and favourable intermediate-risk disease, the outcome of PACE-C for higher-risk disease is far less certain, due to the possibility that the necessarily tight treatment margins might increase the risk of local failure. Furthermore, the increased workload involved in the planning and quality assurance of these more complex SABR plans might limit the number of patients who can receive this treatment at each centre.

All of our prostate decision trees still use the original D'Amico classification for localised prostate cancer risk. In the future, as we begin to implement trials that are more specific about the patients they select, we may well see greater use of more nuanced classifications (for example, the Cambridge Prognostic Group system) in clinical practice [39]. This places another limitation on the utility of our model in predicting radiotherapy use in this hypothetical scenario.

*Non-small Cell Lung Cancer*

In contrast to other cancer sites, the ARR for NSCLC has decreased by 3% compared with our 2017 model. There are multiple important factors contributing to this. First, the proportion of stage IIIA patients undergoing surgery, as opposed to definitive (chemo)radiotherapy or palliative/best supportive care, has increased in recent years [40]. ARR will have been decreased further for this cohort by the near-complete removal of postoperative radiotherapy for stage III-N2 disease following the Lung ART trial results [41]. Second, the regular National Lung Cancer Audit data publication allows accurate modelling of the proportion of inoperable patients. Previously, this model was based on clinicians' consensus but there is widespread regional variation in the management of this patient group and, therefore, this consensus estimate may not have been accurate [25]. We have accounted for a lower proportion of non-surgical patients undergoing definitive radiotherapy compared with the previous model, in keeping with the most recent audit data [25].

Furthermore, there has been a notable shift in stage distribution towards lower stages in recent years, perhaps reflecting greater emphasis on symptom awareness and early lung cancer detection from lung cancer screening trials. This has resulted in a reduction in palliative radiotherapy burden for later stage disease. Further expansion of lung cancer screening trials is expected to decrease the ARR further, as more patients are diagnosed in stage I instead of stage IV.

The overall reduction in ARR masks the significant rise in radiotherapy fraction burden for stage IV NSCLC, given the now accepted radical treatment of thoracic disease and brain oligometastases. Radical treatment of secondary tumours in other sites is increasingly implemented and may become widespread following results of the ongoing SARON trial [42]. Hence, the next model update may see a reversal of this ARR reduction.

There has been a decrease of over 15% in the number of fractions delivered for NSCLC, which is out of proportion to the decline in ARR. This is principally due to the use of SABR for many stage I–II patients who would have previously received conventionally fractionated radiotherapy. Reduced fractionation for stage III definitive radiotherapy (for example, greater use of 20-fraction versus 33-fraction schedules compared with the previous model) has also contributed to the decline in fractions per million in England.

*Head and Neck Cancer*

The updated model output shows that the ARR for head and neck cancer has not changed from the original model update, which is not surprising given that there have not been new indications for radiotherapy. Furthermore, the decision tree branches are categorised broadly (stage I–II or stage III–IV) so even if there were changes to the stage distribution or classification system, this would not have a large effect on the results.

The fractions per million in England have decreased by 863. This is probably the result of multiple small changes to fractionation regimens in various subtypes, largely the removal of 34 fractions and the addition of 30 fractions. This is due to recent stage I–IVb postoperative radiotherapy (after primary surgery) recommendations for oropharynx, nasal cavity/paranasal sinuses, unknown primary, oral cavity, glottic larynx stage III–IV, salivary gland, supraglottic and hypopharynx being 60 Gy in 30 fractions over 6 weeks and a dose of up to 66 Gy in 33 fractions over 6.6 weeks to high-risk subvolumes (areas surrounding extracapsular spread and/or positive/close margins) [13]. Similarly, for stage III–IVb patients undergoing primary radiotherapy and chemotherapy (then surgery), including for oropharynx, supraglottic and hypopharynx cancer, although excluding nasopharyngeal cancer, the recommendation is 70 Gy in 35 fractions over 7 weeks or 65–66 Gy/30 fractions over 6 weeks [13,43–45]. For patients who are fit for and have disease suitable for curative surgery/therapy, but who are either aged over 70 years or are <70 years but due to choice or co-morbidities do not have chemotherapy, the recommendations are 70 Gy in 35 fractions over 6 or 7 weeks, 66 Gy in 33 fractions, 65–66 Gy in 30 fractions over 6 weeks (oropharynx, supraglottic, hypopharynx) and also 60 Gy/54 Gy in 30 fractions over 6 weeks for supraglottic and hypopharynx cancer [13].

## Conclusion

Compared with our previous model, the current version predicts a reduction in fraction demand across England. This is driven principally by hypofractionation of radiotherapy regimens, using technology that requires increasingly complex planning. Treatment complexity and local service factors need to be taken into account when

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translating fraction burden into linear accelerator demand or throughput.

## Conflicts of Interest

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## Author Contributions

TM, KK and RJ are guarantors of integrity of the entire study. SH, SS, TM and RJ were responsible for study conceptions and design. SH and SS carried out the literature research. SH, SS, TM and RJ were responsible for experimental studies/data analysis.

TM and NK carried out the statistical analysis. SH, SS, TM and RJ prepared the manuscript.

SH, SS, NK, KK, TM and RJ edited the manuscript.

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