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## Clinical Investigation

# Hospital Quality Factors Influencing the Mobility of Patients for Radical Prostate Cancer Radiation Therapy: A National Population-Based Study

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## Summary

Using geographic information systems and econometric modeling, we present the first national study evaluating the hospital quality factors that attract patients

**Purpose:** To investigate whether patients requiring radiation treatment are prepared to travel to alternative more distant centers in response to hospital choice policies, and the factors that influence this mobility.

**Methods and Materials:** We present the results of a national cohort study using administrative hospital data for all 44,363 men who were diagnosed with prostate cancer and underwent radical radiation therapy in the English National Health Service between 2010 and 2014. Using geographic information systems, we investigated the extent to which men choose to travel beyond ("bypass") their nearest radiation therapy

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the authors and not necessarily those of the NHS, the National Institute for Health Research, or the Department of Health.

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Data for this study are based on patient-level information collected by the NHS, as part of the care and support of cancer patients. The data are collated, maintained, and quality assured by the National Cancer Registration and Analysis Service, which is part of Public Health England. Access to the data was facilitated by Public Health England's Office for Data Release.

Conflict of interest: H.P. has worked as a consultant and has been paid for lectures and received hospitality to travel to meetings from Janssen, Astellas, Ferring, Sanofi Aventis, and Novartis.

Supplementary material for this article can be found at [www.redjournal.org](http://www.redjournal.org).

for radiation therapy treatment in health care markets. We found that 1 in 5 men bypassed their nearest radiation therapy center for treatment, especially those who were younger and more affluent. In the absence of indicators reflecting treatment quality, centers that were early adopters of intensity modulated radiation therapy or that offered shorter hypofractionated treatment schedules were more attractive to patients.

center, and we used conditional logistic regression to estimate the effect of hospital and patient characteristics on this mobility.

**Results:** In all, 20.7% of men ( $n=9161$ ) bypassed their nearest radiation therapy center. Travel time had a very strong impact on where patients moved to for their treatment, but its effect was smaller for men who were younger, more affluent, and from rural areas ( $P$  for interaction always  $<.001$ ). Men were prepared to travel further to hospitals that offered hypofractionated prostate radiation therapy as their standard schedule (odds ratio 3.19,  $P<.001$ ), to large-scale radiation therapy units (odds ratio 1.56,  $P<.001$ ), and to hospitals that were early adopters of intensity modulated radiation therapy (odds ratio 1.37,  $P<.001$ ).

**Conclusions:** Men with prostate cancer are prepared to bypass their nearest radiation therapy centers. They are more likely to travel to larger established centers and those that offer innovative technology and more convenient radiation therapy schedules. Indicators that accurately reflect the quality of radiation therapy delivered are needed to guide patients' choices for radiation therapy treatment. In their absence, patient mobility may negatively affect the efficiency and capacity of a regional or national radiation therapy service and offer perverse incentives for technology adoption. © 2017 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

## Introduction

Many countries have introduced policies that allow patients to choose the hospital where they have their treatment (1, 2). Patients are expected to choose a hospital that delivers better-quality care, and the resultant competition between providers as they attempt to attract new patients is expected to stimulate improvements in quality. However, for complex treatments such as radiation therapy we have no data to support whether patients are prepared to travel to alternative, more-distant centers, or the quality factors that influence this.

It is also debatable whether such policies are relevant in cancer care, given the increasing centralization of cancer services, which by its nature will reduce the choices available to patients (3, 4). Treatment decisions are complex, and the therapy itself may last for months, resulting in significant physical and financial burden for those considering treatment at a more-distant hospital. Furthermore, there is a lack of valid performance indicators that accurately reflect the quality of cancer treatment, especially radiation therapy.

However, radiation therapy has seen a relentless diffusion of new technologies over the last decade, which has shaped clinical practice in both the targeting and delivery of treatment. It has been suggested that in certain health care markets, clinicians and hospital providers are encouraged to diversify practice through the integration and marketing of new high-cost technologies (eg, proton beam therapy), to attract new patients. However, this has been largely anecdotal, with little or no evidence in publicly funded health systems (5, 6).

Using linked patient-level national datasets, geographic information systems, and applied econometric modeling,

we investigated whether prostate cancer patients who had radical radiation therapy in the English National Health Service (NHS) “bypassed” their nearest radiation therapy provider for treatment, as well as the provider and patient characteristics associated with that mobility.

The NHS provides an ideal system for understanding the impact of patient choice policies. It is a national, single-payer, tax-based system in which care is free and not based on ability to pay for insurance or treatment. The costs of services are fixed under a national tariff, and providers are therefore expected to compete on quality and not price (7). Patients have access to all available NHS providers in England, with no explicit restrictions on the choices available.

## Methods and Materials

We obtained individual patient-level data on all patients diagnosed with prostate cancer between January 1, 2010, and March 31, 2014 who subsequently underwent radiation therapy in the English NHS. Data were retrieved from the National Cancer Registration and Analysis Service and linked at patient level to the National Radiotherapy Dataset and Hospital Episode Statistics (8, 9). Patients who underwent radiation therapy in the private sector were not included in the analysis ( $<10\%$  of eligible patients).

The National Radiotherapy Dataset provided information on each patient's radiation therapy treatment: start and finish dates, treatment site (primary with or without regional nodes), total dose, number of fractions, and radiation therapy technique (intensity modulated radiation therapy vs 3-dimensional conformal radiation therapy). The National Cancer Registration and Analysis Service dataset



provided information on cancer stage and the Hospital Episode Statistics dataset on age and comorbidities. Cancer severity was categorized according to a modified D'Amico classification system (10-12). The patients' place of residence was available as the Lower Layer Super Output Area (LSOA), a geographic area that typically includes 1500 residents or 650 households (13, 14).

## Travel times

The population-weighted centroids of the patients' LSOAs (used to define patient residence) and the full postal codes for the hospitals where the radiation therapy was undertaken were inputted into a geographic information system (ESRI ArcGIS 10.3) to calculate travel times according to the fastest route by car (using Ordnance Survey MasterMap Integrated Transport Network).

## Assessment of mobility

All radiation therapy treatment providers ( $n=57$ ) were ranked according to the distance in terms of drive time by car from the patient's residence. The proportion of patients not receiving care at their nearest provider (ranked  $>1$ ) were considered to be "by-passers" (15).

We identified for each radiation therapy center the number of patients for whom that center was nearest but who had their treatment elsewhere—"leavers"—and also those patients for whom another radiation therapy center was nearest but who had their radiation therapy at that center—"arrivers." A center was identified as being a "winner" or "loser" of patients if the difference between arrivers and leavers was statistically significant (16). Patients receiving radiation therapy at their nearest center were defined as "core users."

## Competition indices

For each center we also calculated a spatial competition index (SCI) as a measure of "external competition" (17, 18). The SCI provides a uniform metric that can be used across all centers in England to factor in the demand for services and the availability of alternative hospitals for patients to choose. In this analysis the SCI for a radiation therapy center was calculated according to both the number of eligible patients within a 60-minute drive and the number of alternative radiation therapy centers within a 60-minute drive for each eligible patient:

$$SCI_i = 1 - \frac{1}{n_i} \sum_{j=1}^{n_i} \frac{1}{k_{ji}}$$

where radiation therapy center  $i$  has  $n$  eligible patients within a 60-minute drive and patient  $j$  in center  $i$  has  $k$  alternative radiation therapy centers within a 60-minute drive. The SCI ranges theoretically from 0 for centers in a monopoly environment to a value close to 1 for centers in the most competitive environment.

## Patient characteristics

Four patient-level variables were derived from the linked dataset. First, patient age at the time of prostate cancer diagnosis. Second, the Royal College of Surgeons Charlson Score was used to identify the number of comorbidities (19). Third, the Index of Multiple Deprivation (IMD) was used as a measure of the patients' socioeconomic deprivation (20). The IMD was stratified into quintiles according to the national distribution, such that 1 represents households in the 20% least deprived and 5 in the 20% most deprived LSOAs. Fourth, the patients' area of residence was classified as urban or rural (21).

## Hospital characteristics

At the start of the study there were 52 radiation therapy centers across England. A further 5 centers opened during the study period. In the absence of publicly reported performance indicators for prostate cancer radiation therapy, we created 4 hospital-level variables as proxies for quality, which may make a hospital more attractive to patients when considering where to have radiation therapy treatment. These variables were informed by the peer-reviewed literature, in-depth qualitative interviews undertaken by the study team with men previously treated for prostate cancer in the United Kingdom, and The National Prostate Cancer Audit organizational survey (22).

We identified the 28 "university teaching hospitals," on the basis of their membership of the Association of UK University Hospitals (23). Studies have demonstrated that teaching hospital status is associated with higher quality for certain interventions compared with non-teaching hospitals and therefore may be preferentially chosen by patients (24-28).

Second, we labeled the 3 hospitals that were delivering intensity modulated radiation therapy (IMRT) as a standard of care at the start of the study period (2010) as "early IMRT adopters." There was emerging evidence at the time that this technique delivered improved outcomes (reduced pelvic toxicity) relative to standard 3-dimensional conformal techniques (29, 30). In addition, IMRT was already a standard of care in countries such as the United States in 2010, which may have prompted patients to seek treatment at centers that offer this technique in the NHS (29, 30).

Third, we identified 8 centers that we classified as "large-scale radiation therapy units" on the basis of the number of linear accelerators on site. The median number of linear accelerators across the 57 English NHS radiation therapy centers was 4 (range, 2-12) (31). Centers with  $\geq 8$  linear accelerators on site (ie, in the top quintile based on the distribution of linear accelerators) were considered to meet this criteria. These centers may have been considered preferentially by patients owing to their large capital and staff infrastructure investment toward radiation therapy facilities or wider reputation effects from being regional centers.

Fourth, we identified 4 centers that were delivering hypofractionated radiation therapy (ie, higher dose per treatment delivered over fewer total number of attendances) as their standard dose-fractionation regimen for prostate cancer at the start of the study period in 2010. Although a dose of 74 Gy delivered over 37 treatments remains the standard of care, hypofractionated regimens halve the duration of treatment, from 8 weeks to 4 weeks (32, 33).

## Statistical analysis

We used conditional logit regression to model the odds that a patient moved to a particular hospital as a function of travel time and hospital and patient characteristics (34, 35). We created a data set that included for each patient a row for each hospital providing prostate cancer radiation therapy at the time of treatment (number of hospitals varied between 52 and 57 because 5 hospitals opened during the study period). The dependent variable of the conditional logit model was a dummy variable with a value of 1 for the hospital where a patient had his treatment and a value of 0 otherwise.

Travel time was included in the model as the additional time men had to travel beyond their nearest hospital to an alternative hospital providing radiation therapy. In this way we accounted for the variation in service configuration across England. Per definition, additional travel time was 0 minutes if a patient had his radiation therapy in the nearest radiation therapy center.

First, we modeled the effect of travel time and individual hospital characteristics on the odds of moving to a particular hospital as part of a univariate analysis. In the second model, we included both hospital characteristics and travel time as part of a multivariate conditional regression model. In the third model, we included travel time, hospital characteristics, and the interactions of patient characteristics with travel time. Patient characteristics included age, comorbidity, socioeconomic background, and urban or rural residence. (We present the results of both models in Tables 3 and 4.) Stata version 14 was used to undertake the statistical analyses (StataCorp, College Station, TX).

## Results

### Patient population

We identified 46,654 men diagnosed with prostate cancer between January 1, 2010, and March 31, 2014 who subsequently received radiation therapy (Supplementary Material Appendix 1; available online at [www.redjournal.org](http://www.redjournal.org)). Of these men, 44,860 received radical radiation therapy. A total of 497 men were excluded because they lived outside England or could not be assigned to an NHS radiation therapy provider. The final study cohort comprised 44,363 men, and patient characteristics are presented in Table 1.

**Table 1** Characteristics of 44,363 men undergoing radical radiation therapy between 2010 and 2014 in the English National Health Service

Characteristic	n	%
Age (y)		
<65	12,951	29.2
65-69	9453	21.3
70-74	12,373	27.9
≥75	9586	21.6
Cancer severity		
Advanced	620	1.8
Locally advanced	19,037	55.6
Intermediate localized	13,292	38.8
Low-risk localized	1276	3.7
Insufficient staging information (n = 10,138)		
No. of comorbidities		
0	34,368	77.5
≥1	9995	22.5
Index of multiple deprivation (national quintiles)		
1 (least deprived)	10,832	24.4
2	10,780	24.3
3	9651	21.8
4	7336	16.5
5 (most deprived)	5764	13.0
Urban rural classification*		
Urban	33,332	75.1
Rural	11,031	24.9

\* See text for definition.

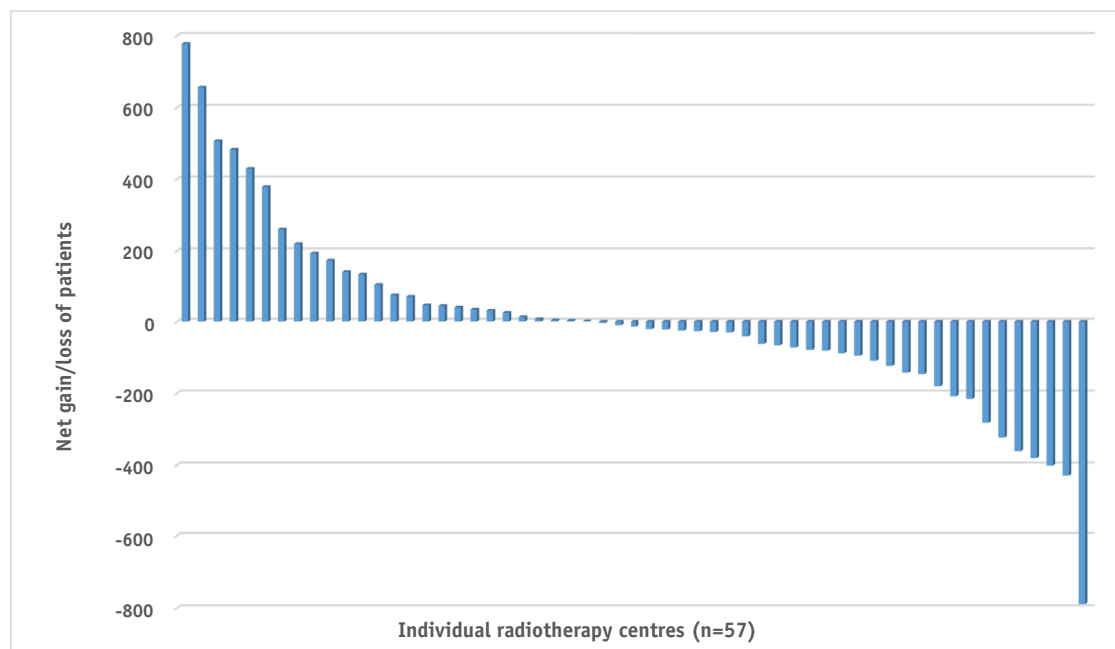
### Patient mobility

In all, 9161 men (20.7%) “bypassed” or traveled beyond their nearest radiation therapy center to an alternative, more-distant center (Table 2); 5142 men (12.6%) bypassed only 1 center, and 1125 men (2.5%) bypassed 5 or more centers for treatment (Table 2). Figure 1 demonstrates the net gains and losses of patients by individual prostate cancer radiation therapy centers (n=57) due to patient mobility during the study period. Of the 57 centers, 19 (33.3%) were classified as “winners” and 25 (43.9%) as “losers”; 13 centers had no statistically significant net gain

**Table 2** Patient mobility of 44,363 men undergoing radical radiation therapy between 2010 and 2014 in the English National Health Service: Number of hospitals “bypassed” and median travel time

No. of hospitals bypassed*	No. of patients (%)	Travel time (min), median (interquartile range)
0	35,202 (79.4)	20.7 (12.1-32.7)
1	5142 (12.6)	38.3 (23.4-53.6)
2	1764 (4.0)	44.0 (22.9-59.6)
3	822 (1.9)	46.7 (34.7-60.6)
4	308 (0.7)	55.6 (43.3-67.3)
≥5	1125 (2.5)	52.9 (36.8-89.8)

\* Hospitals are considered to be “bypassed” if a man has radiation therapy in a hospital that is further away from his place of residence in terms of travel time by car.



**Fig. 1.** Net gains and losses of patients by each radiation therapy center (blue bars) due to patient mobility between 2010 and 2014. (A color version of this figure is available at [www.redjournal.org](http://www.redjournal.org).)

or loss of patients. Some of the “winners” were treating 500 or more patients than expected if they had been operating solely on men for whom they were the nearest center. Conversely, some of the “losers” were treating nearly 400 fewer procedures than expected. When considering the degree of external competition faced by each center, centers experiencing the largest net gains or losses were predominantly located in the most competitive areas (SCI between 0.70 and 1) (Fig. 2).

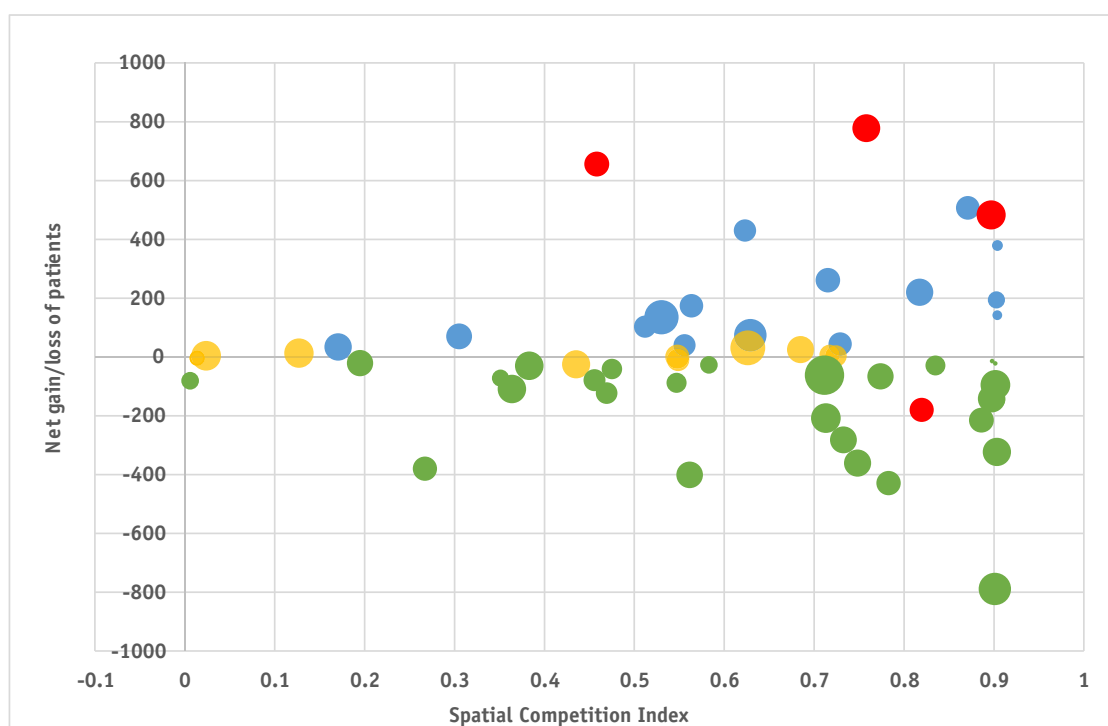
### Impact of travel time and patient and hospital characteristics on patient mobility

Travel time had a very strong impact on the odds that a patient traveled to a particular hospital to receive radiation therapy in the univariate and multivariate conditional regression models (Tables 3 and 4). The odds of a patient traveling to a hospital that was up to 10 minutes further away than the patient’s nearest radiation therapy provider was found to be on average 72% smaller (odds ratio [OR] of 0.28) according to a conditional logit model that only included additional travel time (Table 3, model 1). The odds of a patient traveling to a particular hospital decreased markedly as the additional travel time increased.

The results of the univariate analysis assessing the impact of hospital characteristics on the odds of traveling further to a particular hospital are presented in Table 3 (model 1). When considering the impact of hospital characteristics on mobility patterns of patients as part of a multivariate regression model including travel time and patient characteristics, men were 3.19 times more likely to travel to a particular radiation therapy center if it offered hypofractionated radiation therapy as standard (Table 4,

model 3). In addition, patients were 1.56 times more likely to travel to a center classified as a large-scale radiation therapy unit, and 1.37 times more likely to travel to a center if it was an established IMRT center. There was a small but significant increase in the likelihood that patients traveled to a specific center if it had university hospital status (OR 1.19).

The addition of patient characteristics as interaction terms into our model showed that the impact of travel time was smaller for men who were younger and for those who lived in more affluent or rural areas, because the ORs expressing the interaction terms are greater than 1 (Table 4, model 3). The greater the size of the interaction term value, the larger its attenuating effect on the impact of travel time. For example, compared with having the radiation therapy at the nearest provider, for men classified as living in urban and less affluent areas, who are aged  $\geq 65$  years, and who have comorbidities, the odds of traveling to a hospital that was up to 10 minutes further away was estimated to be 82% smaller (OR 0.18). The corresponding figure for men from rural areas (keeping all other patient characteristics the same as described) was 60% smaller (OR 0.40 =  $0.18 \times 2.23$ , based on multiplying the OR of the main effect of additional travel time with the OR of the interaction term). This implies that men from rural areas have a greater odds of traveling to an alternative hospital up to 10 minutes further away compared with men from urban areas. Different patient characteristics attenuate the effect further. For example, men from both rural and affluent areas (positive interaction terms) have an even greater odds of traveling to an alternative hospital up to 10 minutes further away (keeping all other patient characteristics the same, OR 0.51 =  $0.16 \times 2.23 \times 1.26$ ) compared with men from urban and less affluent areas.



**Fig. 2.** Graph demonstrating the impact of competition (measured by the spatial competition index [SCI]) on the net gain or loss of patients for radiation therapy centers between 2010 and 2014. SCI score = 0: Hospital facing weakest competition; SCI score = 1: Hospital facing strongest competition; size of circle = number of men expected to have radiation therapy at center; blue = centers classified as “winners”; green = centers classified as “losers”; orange = centers with no statistically significant gain or loss of patients; red = centers offering hypofractionated radiation therapy as standard.

## Discussion

There is limited evidence about what factors inform and influence cancer patients' choice of treatment provider (1). In this study we demonstrate that in the United Kingdom NHS, 1 in 5 patients who have radiation therapy treatment

“bypass” their nearest radiation therapy center. Travel time had a very strong impact on where patients received their treatment, but this effect was smaller for men who were younger, more affluent, or living in rural areas. Men were more likely to travel to centers that offered shorter hypofractionated radiation therapy regimens as standard for

**Table 3** Impact of travel time and hospital characteristics on patient mobility in 44,363 men undergoing radical radiation therapy between 2010 and 2014 in the English National Health Services

Parameter	Unadjusted OR (model 1)*	95% CI	$P^{\dagger}$	Adjusted OR (model 2) <sup>‡</sup>	95% CI	$P^{\dagger}$
Impact of additional travel time (min)	1		<.001	1		<.001
<10	0.28	0.27-0.29		0.27	0.26-0.28	
11-30	0.07	0.06-0.07		0.06	0.05-0.06	
31-60	0.006	0.005-0.06		0.005	0.004-0.005	
>60	0.0002	0.0001-0.0002		0.0002	0.0001-0.0002	
Impact of hospital characteristics						
University hospital	1.28	1.26-1.31	<.001	1.18	1.14-1.23	<.001
Large-scale RT unit	1.95	1.91-1.99	<.001	1.55	1.48-1.62	<.001
Early adopter of IMRT	1.15	1.11-1.20	<.001	1.37	1.30-1.46	<.001
Hypofractionated treatment (standard)	1.73	1.68-1.78	<.001	3.10	2.92-3.28	<.001

Abbreviations: CI = confidence interval; IMRT = intensity modulated radiation therapy; OR = odds ratio; RT = radiation therapy.

\* Model 1 presents unadjusted ORs from the univariate analysis assessing the impact of additional travel time and hospital characteristics on the odds that a patient travels to a particular hospital.

<sup>†</sup>  $P$  value based on likelihood ratio test.

<sup>‡</sup> Model 2 presents adjusted ORs from the multivariate conditional logit analysis assessing the impact of both additional travel time and hospital characteristics on the odds that a patient travels to a particular hospital.

**Table 4** Impact of travel time and hospital and patient characteristics on patient mobility in 44,363 men undergoing radical radiation therapy between 2010 and 2014 in the English National Health Service

Parameter	Adjusted OR (model 3)*	95% CI	P†
Impact of additional travel time (min)‡	1		<.001
<10	0.18	0.16-0.20	
11-30	0.04	0.04-0.05	
31-60	0.002	0.002-0.003	
>60	0.00006	0.00004-0.00009	
Impact of hospital characteristics			
University hospital	1.19	1.14-1.23	<.001
Large-scale RT unit	1.56	1.49-1.63	<.001
Early adopter of IMRT	1.37	1.30-1.45	<.001
Hypofractionated treatment (standard)	3.19	3.01-3.37	<.001
Difference in impact of additional travel time for selected patient characteristics§	Interaction terms		
Younger patients (<65 y)			<.001
<10	1.17	1.07-1.28	
11-30	1.10	1.00-1.21	
31-60	1.42	1.15-1.76	
>60	2.01	1.46-2.77	
Patients without comorbidities			NS
<10	0.95	0.87-1.03	
11-30	0.93	0.85-1.02	
31-60	0.96	0.79-1.17	
>60	1.24	0.94-1.63	
Patients from more affluent areas (IMD 1 or 2)			<.001
<10	1.26	1.17-1.36	
11-30	1.20	1.10-1.29	
31-60	1.08	0.92-1.29	
>60	1.31	1.05-1.62	
Patients from rural areas			<.001
<10	2.23	2.04-2.44	
11-30	2.21	2.03-2.42	
31-60	3.21	2.72-3.79	
>60	1.87	1.51-2.33	
McFadden's pseudo R <sup>2</sup>	0.82		

Abbreviations: IMD = Index of Multiple Deprivation; NS = nonsignificant. Other abbreviations as in Table 3.

\* Model 3 presents adjusted odds ratios from the multivariate conditional logit analysis assessing the impact of additional travel time, hospital characteristics, and patient characteristics on the odds that a patient travels to a particular hospital.

† P value based on likelihood ratio test.

‡ Note that the adjusted ORs for the impact of additional travel time in model 3 relates to a particular patient group: older men (≥65 years), with comorbidity (Charlson ≥1), from less affluent (IMD 3-5) and urban areas.

§ The impact of selected patient characteristics on additional travel time is presented as interaction terms. These should be multiplied with the corresponding adjusted OR for additional travel time to formulate a new OR. Interaction terms can be used in any combination to assess the effect of different patient characteristics on the odds that a patient travels to a particular hospital. For example, the adjusted ORs presented (‡) relate to older men (≥65 years), with comorbidity (Charlson ≥1), from less affluent (IMD 3-5) and urban areas. To calculate the new OR for younger and more affluent men traveling 11-30 minutes, but who still have comorbidity and live in urban areas, multiply 0.04 (travel time adjusted OR for 11-30 minutes) by the corresponding interaction term for men who are affluent (1.20) and men living in rural areas (2.21). The new odds ratio is  $0.04 \times 1.20 \times 2.21 = 0.11$ . That is, men with these patient characteristics have a greater odds of traveling up to 30 minutes to a particular hospital.

prostate cancer, larger established radiation therapy units, and those centers that utilized IMRT earlier. Mobility between providers resulted in winners and losers, with some centers treating hundreds more patients each year than expected if they only treated local patients.

These findings are relevant across a range of elective secondary care cancer services in countries that have introduced patient choice of provider policies (1). A substantial number of patients were prepared to bypass their

nearest radiation therapy center despite the absence of comparative provider-level performance information relating to the quality of radiation therapy treatment and the prolonged duration of treatment.

The routine availability of hypofractionated radiation therapy for prostate cancer was the strongest hospital-level driver of patient mobility. It is not possible to say whether patients were prepared to travel further to these centers because hypofractionated radiation therapy is more



convenient or because patients considered these centers to be innovative and therefore potentially better (36). However, the potential desire for treatment of shorter duration correlates with our study findings that travel time has a very strong impact on the choices that patients make. In addition, previous research has shown that patients are reluctant to undergo radiation therapy compared with other prostate cancer treatment modalities, owing to its prolonged duration (37).

Patients in our cohort were more likely to travel to the 3 centers labeled as early adopters of IMRT, despite rapid expansion in the availability of IMRT across centers in England during the study period (38, 39). This suggests that there is a wider reputation effect associated with being an early adopter of innovation and that patients may have considered these centers to be at the forefront of technology (40, 41). To illustrate this point, all 3 established IMRT centers were also amongst the first adopters of stereotactic body irradiation in England (12). Similarly, patients were more likely to travel to larger-scale radiation therapy units, which may have had a wider reputation as being a regional center of excellence for radiation therapy or cancer care more generally.

The patterns of mobility observed has resulted in large and unexpected shifts in market share. Radiation therapy centers located in the most competitive areas had significant gains and losses of patients (Fig. 2). In the NHS, funding follows the patient (7), and therefore centers losing patients may have to cease providing that service owing to lost income. Such an eventuality has already transpired for surgical centers providing radical prostatectomy, several of which have closed in the last 5 years (42). This pattern of winners and losers also highlights the inefficiency and wasted capacity within the current radiation therapy service, which may further increase as a result of the current drive toward opening new radiation therapy centers across England (5 opened during the study period) to improve access to treatment. Equally, the impact on service capacity (eg, waiting times) needs to be considered for those centers treating significant numbers of out-of-area patients.

### Appropriate implementation of advanced radiation technologies

In the absence of performance indicators, centers that diversify their clinical practice (eg, through the integration of new technology) are potentially more attractive to patients. In the United States, competition has been a key driver in the rapid expansion of innovative radiation therapies, such as IMRT, proton beam therapy, and Cyberknife, for the management of prostate cancer to maintain market share and attract new patients. This has occurred at significant additional cost without any clear evidence for benefits to patients over existing standards of care (6,30,43-46).

To avoid similar patterns of technology adoption for radiation therapy across different health systems, we recommend the use of formal health technology assessment

processes to support decision making regarding the integration of new technologies in publicly funded systems (5, 47). In contrast to new cancer drugs, radiation therapy has remained beyond the remit of health technology assessment (5). The Health Economics in Radiation Oncology project, which is being carried out under the auspices of the European Society for Radiotherapy and Oncology, is attempting to define economic frameworks for assessing the clinical and economic benefit of new radiation therapy technologies and is still in its infancy (48).

There is also a necessity to develop valid performance indicators for radiation therapy to guide patient decision making and potentially stimulate improvements in treatment outcomes through “quality competition” as patients are responsive to perceived differences in quality (49). This is important, given the increasing reliance on unsubstantiated web- and media-based cancer information, especially for new technologies (50-52). A series of process indicators have been proposed by professional bodies, but these are hard for patients to interpret (53, 54). Although outcome measures are preferable, an important caveat is that these can only be published following a lag period (toxicity measures at 1 and 5 years) (55).

### Methodologic limitations

Our modelling of patient mobility used centroids of the LSOAs, small geographic regions typically made up of approximately 650 households, to represent the location of the patients' residence. This approach has been used in previous studies of patient mobility in England (56). However, it is likely that the “noise” added to the travel times will have attenuated rather than enhanced the observed relationships. Our model uses average drive times, which is the standardized methodology for these analyses and considered superior to straight-line distance. However, we do acknowledge that drive times are variable depending on the time of day, which may affect patients' decision making. In addition, public transport times were not available for this analysis.

We have not included waiting times as a factor influencing provider choice, because these were not publicly available for individual centers. Some patients may have considered moving to alternative providers to receive quicker treatment; however, extensive efforts have been made in the English NHS to ensure prompt diagnosis and treatment of suspected cancer patients through a system of defined targets (57, 58). In 2014/2015 95.3% of people treated for urologic cancers in the NHS began their first definitive treatment within the 31-day target (59). Other potential determinants of mobility, such as care giver/work location, were not available in our dataset, and we were unable to assess the effect of disease severity owing to incomplete staging data. However, the overall impact on our observed patterns of mobility is likely to be small in the context of up to 20% of patients bypassing their

nearest provider. The overall predictive probability of our model, despite these exclusions, is very high, 82% (note models with values above 60% for goodness of fit estimation are considered to have a high degree of explanatory power) (60).

## Conclusions

Men with prostate cancer are prepared to bypass their nearest provider for radical radiation therapy, particularly those who are younger and more affluent. They are more likely to travel to larger established centers and those that offer innovative technology and shorter radiation therapy schedules. Patient mobility varies significantly across regions and between centers and is mainly evident in areas where competition between providers is strongest. This in itself implies that competition as a mechanism to stimulate improvements in the quality of care can only work in specific parts of the country. Indicators that accurately reflect the quality of radiation therapy delivered are essential to guide patients' choices for radiation therapy treatment. In their absence, patient mobility may negatively affect the efficiency and capacity of regional or national radiation therapy services and offer perverse incentives for technology adoption even in publicly funded health systems.

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