Radiotherapy and Oncology 192 (2024) 110092

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Original Article

The impact of transportation mode, socioeconomic deprivation and rurality on travel times to radiotherapy and surgical services for patients with prostate cancer: A national population-based evaluation

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A B S T R A C T

Background: The distances that patients have to travel can influence their access to cancer treatment. We investigated the determinants of travel time, separately for journeys by car and public transport, to centres providing radical surgery or radiotherapy for prostate cancer.
Methods: Using national cancer registry records linked to administrative hospital data, we identified patients who had radical surgery or radiotherapy for prostate cancer between January 2017 and December 2018 in the English National Health Service. Estimated travel times from the patients' residential area to the nearest specialist surgical or radiotherapy centre were estimated for journeys by car and by public transport.
Results: We included 13,186 men who had surgery and 26,581 who had radiotherapy. Estimated travel times by public transport (74.4 mins for surgery and 69.4 mins for radiotherapy) were more than twice as long as by car (33.4 mins and 29.1mins, respectively). Patients living in more socially deprived neighbourhoods in rural areas had the longest travel times to the nearest cancer treatment centres by car (62.0 mins for surgery and 52.1 mins for radiotherapy). Conversely patients living in more affluent neighbourhoods in urban conurbations had the shortest (18.7 mins for surgery and 17.9 mins for radiotherapy).
Conclusion: Travel times to cancer centres vary widely according to mode of transport, socioeconomic deprivation, and rurality. Policies changing the geographical configuration of cancer services should consider the impact on the expected travel times both by car and by public transport to avoid enhancing existing inequalities in access to treatment and patient outcomes.

Introduction

The centralisation of cancer services to high-volume centres across Europe and internationally has been undertaken for several cancer-specific surgical procedures based on evidence that centres performing higher volumes deliver better patient outcomes [1]. Whilst the rationale for centralisation of many types of cancer surgery has been established, there is also increasing evidence of a volume-outcome relationship to support centralisation of radiotherapy services, particularly for complex tumour types, such as head and neck cancer. [2].

The potential benefits of service centralisation to improve the quality of care needs to be balanced against an increase in travel times for some patients [3,4]. For treatment modalities such as radiotherapy with daily treatments for up to six weeks, this can result in patients either choosing not to receive treatment [5,6], or alternative modalities [7]. There is also a substantial environmental impact from patient travel. In 2019, staff commute and patient and visitor travel contributed to 10 % of total NHS CO_2 emissions [8].

Ensuring equitable access to care is a central pillar of health service policy at both member state and European Union level which needs to consider the distance from the patient's residence to the healthcare facility that provides the service, as well as the modes of transport that are available. Despite the central importance of transportation mode on accessing health services, there has been limited evaluation of this critical factor on access to treatment and whether this disproportionately affects patients living in more deprived areas or particular parts of

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https://doi.org/10.1016/j.radonc.2024.110092
Received 8 September 2023; Received in revised form 9 January 2024; Accepted 9 January 2024
Available online 12 January 2024

the country [9,10].

Most of the literature has focused on uptake of cancer screening, finding that lower rates of screening uptake are associated with a dependence on public transport to access healthcare facilities [11–13]. Given the concern regarding difficulties in accessing care in the era of centralisation [14], an empirical investigation to assess the geographical variation in access to specific cancer services and its potential impact on equity are essential for informing policy.

In this national population-based study in England, we evaluated differences in travel time by car and public transport for two major prostate cancer treatment modalities: surgery and radiotherapy. Both treatment services have been centralised with 50 surgical units and 60 radiotherapy units in England at present [15]. The study analysed whether patients living in rural areas or in more deprived areas face longer travel times whether using public transport or car than patients living in urban or more affluent areas.

Materials and methods

Data sources and study population

This study used English Cancer Registry data, Hospital Episode statistics (HES) and the National Radiotherapy Dataset (RTDS), linked at patient level, to identify all men who were diagnosed with non-metastatic prostate cancer between 1 January 2017 and 31 December 2018 and treated with radical prostatectomy or radical radiotherapy in the 50 NHS hospitals that routinely perform prostate cancer surgeries or received radiotherapy treatment in the 60 NHS hospitals identified as radiotherapy centres. Patients who received cancer treatments in the private sector were not included in the analysis.

The International Classification of Diseases 10th Edition (ICD-10) code C61 was used to identify men with prostate cancer in the cancer registry data set [16]. This data source also provided the patient's age at diagnosis, date of diagnosis, and cancer stage.

The linked Hospital Episode Statistics (HES) [17], the administrative database of all care episodes in English NHS hospitals, provided information on patient's ethnicity, and number of comorbidities in the 2 years preceding diagnosis according to the RCS Charlson score [18]. In addition, it provided socioeconomic deprivation expressed in terms of quintiles of the national distribution of the Index of Multiple Deprivation (IMD) of the patient's residential location represented by 32,844 Lower Layer Super Output Areas (LSOA) which are geographical footprints representing up to 1500 people or 650 households [19].

HES inpatient records provided information on the treating NHS hospital site, the date of admission for the major cancer surgery, the mode of admission (i.e., elective or urgent), and the type of resection [18]. Patients who had a radical prostatectomy were identified according to codes listed by the Office of Population Censuses and Surveys Classification of Surgical Operations and Procedures, 4th Revision (OPCS-4) [20]. The radiotherapy dataset (RTDS) provided information on the treating hospital, the date of treatment as well as information on the dose of radiotherapy treatment and number of attendances which was used to identify patients receiving radical treatment.

Travel time

Travel time from the patient residence to the hospital providing radiotherapy or surgery was estimated using a geographic information system. The location of patient residence was represented by the population-weighted centroids of their LSOAs. There are 32,844 LSOAs in England, defined as small geographic areas that typically include 1,500 residents or 650 households. The location of the hospitals was derived from their postcode.

Travel time by car (i.e., private car or taxi) to the hospital from the patient residence was defined as the fastest route (in minutes) using the Ordnance Survey Master Map Highways Network.

Transit time by public transport was estimated using the National Public Transport Nodes (NAPTAN) 2019 dataset which includes all public transport access points i.e. anywhere you can get on or off for public transport (including bus, rail, tram, metro, underground) [21]. The access points closest to the patients residence and to the treating hospital were used.

Outcome measures and variables

We considered three study outcomes: travel time by private car, public transport and the difference in travel time between the two travel modes. Explanatory variables included the rurality of patients' residential location defined according to the Office for National Statistics (ONS) Rural/Urban Classification categorised into three broad categories: urban conurbation, urban city and town, rural town and village. Additional explanatory variables included age at diagnosis; ethnic group (men from ethnic minority versus white ethnic background); socioeconomic status (men from more deprived areas (IMD quintiles 3–5) versus men from less deprived areas (IMD quintiles 1–2)); patients' cancer stage (I, II or III) at diagnosis; and men with one or more comorbidity as defined by the Charlson comorbidity index versus men without comorbidity.

Statistical analyses

For patients receiving radical radiotherapy, the three travel time variables were separately analysed by applying univariate and multivariable linear regression models to estimate crude and adjusted associations with the pre-specified patient factors. The travel times for patients who received a radical prostatectomy were analysed following the same procedure.

A sub-analysis was undertaken to test whether the association between travel times and rurality was modified by patient characteristics by estimating an interaction term between rurality and each of the patient characteristics one at a time in the multivariable regression model. Statistical significance of the interaction term was assessed by the Wald test. Any interaction term estimated with a statistically significant modifying effect ($p < 0.05$) was added into the final multivariable interaction model.

We created a separate category for the missing values in ethnicity and cancer stage to preserve all eligible patients in the linear regressions. This approach to handle missing values was chosen because only a small proportion of observations were missing. Values for ethnicity were not imputed because there could be a systematic rather than a random mechanism underlying missingness of ethnicity data [22].

We also estimated robust standard errors for clustering within cancer alliances (there are 21 Cancer Alliances across England responsible for coordination of cancer services within their geographical catchment area). Data analysis was conducted using Stata 17. Variation in travel time according to geographic location in England were displayed using heat maps created by ArcMap 10.8.

Results

The characteristics of men included in the study are summarised in Table 1. A total of 26,581 men were identified as having received radical radiotherapy following a diagnosis of prostate cancer. The mean age of the cohort was 69.9 (SD = 7.0) years old. 13,186 patients had an elective radical prostatectomy following a cancer diagnosis. The mean age of the cohort was 63.2 (SD = 6.7) years old.

Fig. 1 provides an overview of the travel times for each patient to their nearest radiotherapy or surgical centre by car and the equivalent travel time by public transport. Comparing the best fitted lines for the distribution of travel times across the patient cohort with the diagonals representing equivalent travel time by both modes of transport, patients had longer travels times when accessing treatment services by public

Table 1
Descriptive statistics of patient characteristics.

	Radiotherapy		Prostatectomy	
	n	%	n	%
No. of patients (N)	26,581	100	13,186	100
Age, mean (SD)	69.9 (7.0)		63.2 (6.7)	
18–59	2,417	9.1	3,929	29.8
60–69	8,902	33.5	6,917	52.5
70–79	13,724	51.6	2,333	17.7
80+	1,538	5.8	7	0.1
Ethnicity				
White	23,276	87.6	11,387	86.4
Non-white	1,769	6.7	971	7.4
Not know or missing	1,536	5.8	828	6.3
Charlson comorbidity				
0	22,258	83.7	12,143	92.1
1+	4,323	16.3	1,043	7.9
Stage				
Stage 1	9,309	35.0	3,553	27.0
Stage 2	4,464	16.8	4,223	32.0
Stage 3	11,200	42.1	4,942	37.5
Missing	1,608	6.1	468	3.6
IMD quintiles				
1st	6,860	25.8	3,718	28.2
2nd	6,545	24.6	3,449	26.2
3rd	5,573	21.0	2,714	20.6
4th	4,354	16.4	1,949	14.8
5th (most deprived)	3,249	12.2	1,356	10.3
Rural/Urban classification				
Urban conurbation	8,816	33.2	3,675	27.9
Urban city and town	10,924	41.1	5,862	44.5
Rural	6,841	25.7	3,649	27.7

transport. The mean travel time to the nearest radiotherapy centre by car was 29.1 mins (median: 23.1 mins; interquartile range [IQR]: 13.5–36.7 mins) compared to 69.4 mins by public transport (median: 63.0 mins; IQR: 44.0–84.0 mins). The mean travel time of patients by car to the nearest surgical centre was 33.4 mins (median: 23.6 mins; IQR: 13.6–40.9 mins) compared to 74.4 mins by public transport (median: 64.0 mins; IQR: 45.0–91.0 mins).

Table 2 presents the variation in the differences in travel time between both public and private modes of transport across nine health service regions for surgery and radiotherapy. Nationally, when accessing radiotherapy services, approximately 8 % of patients have travel times in excess of one hour in single trip when using a car and up to 13.4 % of patients living in the South West of England. This increases to 42 % of patients if patients use public transport (59 % for patients living in the North West) with 8 % of patients having in excess of two hours travel time.

Fig. 2a and 2b present the geographical variation in additional travel time for patients using public transport compared to a private car. Regions in the North of England (Northumberland, County Durham), the East (Lincolnshire, Norfolk) and Southwest (Devon, Cornwall) showed the greatest differences with an additional travel time necessary of up to two hours when using public transport compared to private car use in these regions (Appendix Table 1).

For both public and private modes of transport, travel time was statistically significantly associated with age, ethnicity and rurality of residential location in the unadjusted model (Appendix Tables 2 and 3). In the multivariable regression models, rural residents have to travel an additional 15.1 mins by car (95 % confidence interval [95 % CI]: 11.13 to 18.99, $p < 0.001$) and an additional 34.0 mins by public transport (95 % CI: 25.5 to 42.3, $p < 0.001$) compared with those living in urban cities and towns. Patients with an ethnic minority background had on average

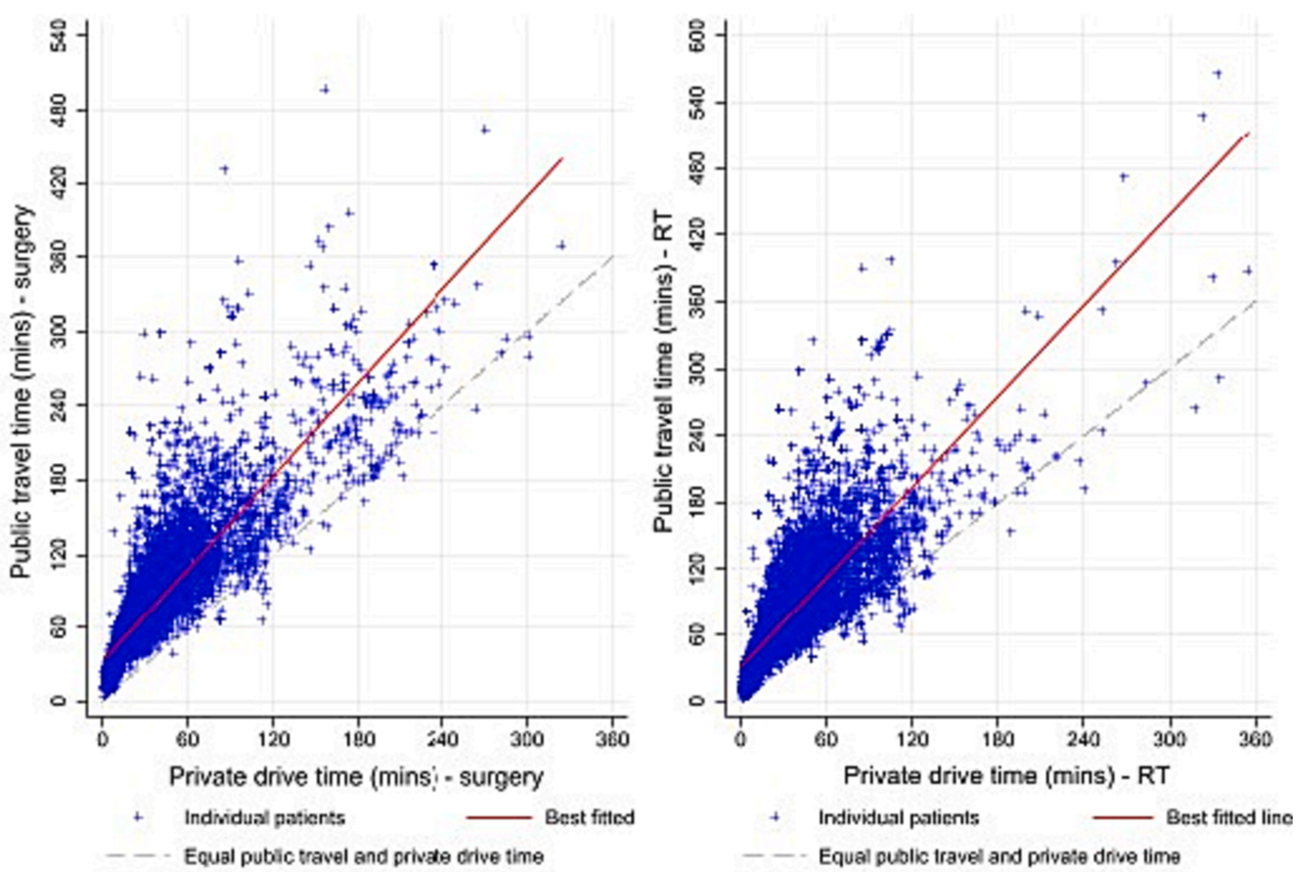

Fig. 1. Scatter plot of travel times for each patient to their chosen surgical centres or radiotherapy (RT) centres by car and the equivalent travel time by public transport.

Table 2
Number of patients (%) who travelled more than one and two hours, by region.

Region	No. of patients	Travel time by car > 1 h	Travel time by car > 2 h	Travel time by public transport > 1 h	Travel time by public transport > 2 h
Surgery					
East Midlands	1,088	156 (14.3 %)	50 (4.6 %)	519 (47.7 %)	219 (20.1 %)
East of England	1,320	318 (24.1 %)	9 (0.7 %)	703 (53.3 %)	262 (19.8 %)
London	1,089	1 (0.1 %)	0 (0 %)	215 (19.7 %)	1 (0.1 %)
North East	617	31 (5.0 %)	2 (0.3 %)	202 (32.7 %)	35 (5.7 %)
North West	1,387	76 (5.5 %)	74 (5.3 %)	575 (41.5 %)	124 (8.9 %)
South East	2,691	305 (11.3 %)	17 (0.6 %)	1,320 (49.1 %)	181 (6.7 %)
South West	1,811	358 (19.8 %)	131 (7.2 %)	667 (36.8 %)	455 (25.1 %)
West Midlands	1,656	85 (5.1 %)	20 (1.2 %)	601 (36.3 %)	153 (9.2 %)
Yorkshire and The Humber	1,527	127 (8.3 %)	13 (0.9 %)	607 (39.8 %)	198 (13 %)
Radiotherapy					
East Midlands	2,705	299 (11.1 %)	8 (0.3 %)	1,282 (47.4 %)	381 (14.1 %)
East of England	3,319	414 (12.5 %)	37 (1.1 %)	1,665 (50.2 %)	589 (17.7 %)
London	3,186	2 (0.1 %)	4 (0.1 %)	300 (9.4 %)	5 (0.2 %)
North East	1,048	49 (4.7 %)	3 (0.3 %)	471 (44.9 %)	50 (4.8 %)
North West	2,688	91 (3.4 %)	20 (0.7 %)	1,601 (59.6 %)	74 (2.8 %)
South East	4,943	458 (9.3 %)	33 (0.7 %)	2,681 (54.2 %)	279 (5.6 %)
South West	3,055	410 (13.4 %)	55 (1.8 %)	1,089 (35.6 %)	480 (15.7 %)
West Midlands	3,072	146 (4.8 %)	14 (0.5 %)	924 (30.1 %)	201 (6.5 %)
Yorkshire and The Humber	2,565	241 (9.4 %)	15 (0.6 %)	1,321 (51.5 %)	370 (14.4 %)

shorter travel times compared with those from a White ethnic backgrounds when using public transport (difference of 8.5 mins (95 % CI: −13.6 to −3.5), p = 0.005) and when travelling by car (difference of 4.4 mins (95 % CI: −7.2 to −1.6), p = 0.009).

The association between rurality of residence and travel times to the nearest radiotherapy centre was significantly modified by area deprivation for both public transport (p = 0.017) and private car (p < 0.001) (Appendix Tables 2 and 3). Using results of the multivariable interaction models, we predicted travel time for each combination of rurality and deprivation categories to show the interacting relationship, based on observed patient characteristics (age, ethnicity, comorbidities and cancer stage) (Fig. 3). Lower socioeconomic groups living in rural areas had the greatest travel burdens across all patient groups. Patients living in more socially deprived neighbourhoods in rural areas had the longest travel times to the nearest radiotherapy centre (52.1 mins by car and 109.5 mins by public transport) and patients living in more affluent neighbourhoods in conurbations the shortest (17.9 mins by car and 52.7 mins by public transport. (Appendix Table 4).

Analysis of travel times for *surgery* showed similar patterns to that observed for radiotherapy treatment. For both public and private modes of transport, travel time was statistically significantly associated with ethnicity and rurality of residential location without adjustment. (Appendix Tables 5 and 6).

In the multivariable regression model, rural residents travelled an additional 20.2 mins by car (95 % CI: 13.1 to 27.3, p < 0.001) and an additional 40.42 mins by public transport (95 % CI: 28.0 to 52.9, P < 0.001)) compared with those living in urban cities and towns. Ethnic minority groups had on average shorter travel times compared with white ethnic groups when using public transport (6.50 mins (95 % CI: −12.2 to −0.8, p = 0.011) and when travelling by car (4.6 mins (95 % CI: −7.8 to −1.4), p = 0.012). As with patients accessing radiotherapy, the association with rurality of residence and travel times to the nearest surgical centre was significantly modified by area deprivation (p = 0.006 for public transport; p = 0.002 for car) (Appendix Fig. 1) Patients living in more socially deprived neighbourhoods in rural areas had the longest travel times to the nearest surgery centre (62.0 mins by car and 121.7 mins by public transport) and patients living in more affluent neighbourhoods in conurbations the shortest (18.7 mins by car and 54.5 mins by public transport) (Appendix Table 7).

Discussion

In the English NHS, patients with prostate cancer face challenges in travelling for essential specialist cancer treatments depending on whether they have access to a car, where they live and their socioeconomic status. In 2021 approximately 25 % of households in England did not have a car, with non-car ownership concentrated in the lowest income households [23,24]. Across Europe there is significant variation in both geographic access to cancer care and access to public or private modes of transportation [25]. We find that travel times by public transport are on average twice as long compared to travel times by car and in some parts of England, particularly rural areas, reliance on public transport was found to extend travel times by a further two hours compared to those with car access. We also find that within rural areas, patients living in the most socially deprived areas face longer travel times than those living in more affluent areas further compounding access disparities.

The observed travel times for those reliant on public transport could impact on the utilisation rates of essential treatments [26–32]. It may also influence the type of treatment chosen by a patient especially where services such as surgery and radiotherapy are not co-located at the same hospital site, necessitating additional travel to access a particular treatment modality (e.g. radiotherapy or surgery) [7,33].

Individuals are expected to face challenges to maintaining work and caregiver responsibilities if parts of the day are consumed by traveling back and forth for treatment, particularly if receiving radiotherapy for 6–8 weeks. Those patients traveling by car face high costs of petrol and car parking [13], and patients living in rural areas are particularly vulnerable to motor fuel price increases [34]. There is also a substantial environmental impact to consider from utilising cancer services. In the UK alone it has been estimated that patient transportation alone for radiotherapy accounts for an estimated 3456 metric tons of carbon dioxide emissions [35].

Our findings have implications which go well beyond UK, and prostate cancer, with evidence of significant access disparities in Canada, Australia, and across Europe particularly for rural dwellers, and both lower income and ethnic minority populations [36]. We would recommend that further health services research considers using public transport times explicitly to inform policy as present models may significantly under-estimate the travel burden on patients to access care.

In the short term, opportunities for furlough and appropriate salary replacement should be considered especially where patients require prolonged courses of daily treatment, particularly for radiotherapy. In the medium term, practices of care across all countries are evolving, particularly for radiotherapy with shorter courses of radiotherapy potentially reducing the treatment pathway from 4 weeks to 1 week [37,38].

Longer term, due consideration must be given for the opening of new satellite radiotherapy services in areas with the longest travel times to care which has been shown to be associated with improved access to treatment [39,40]. To support this quantitative models can be used to

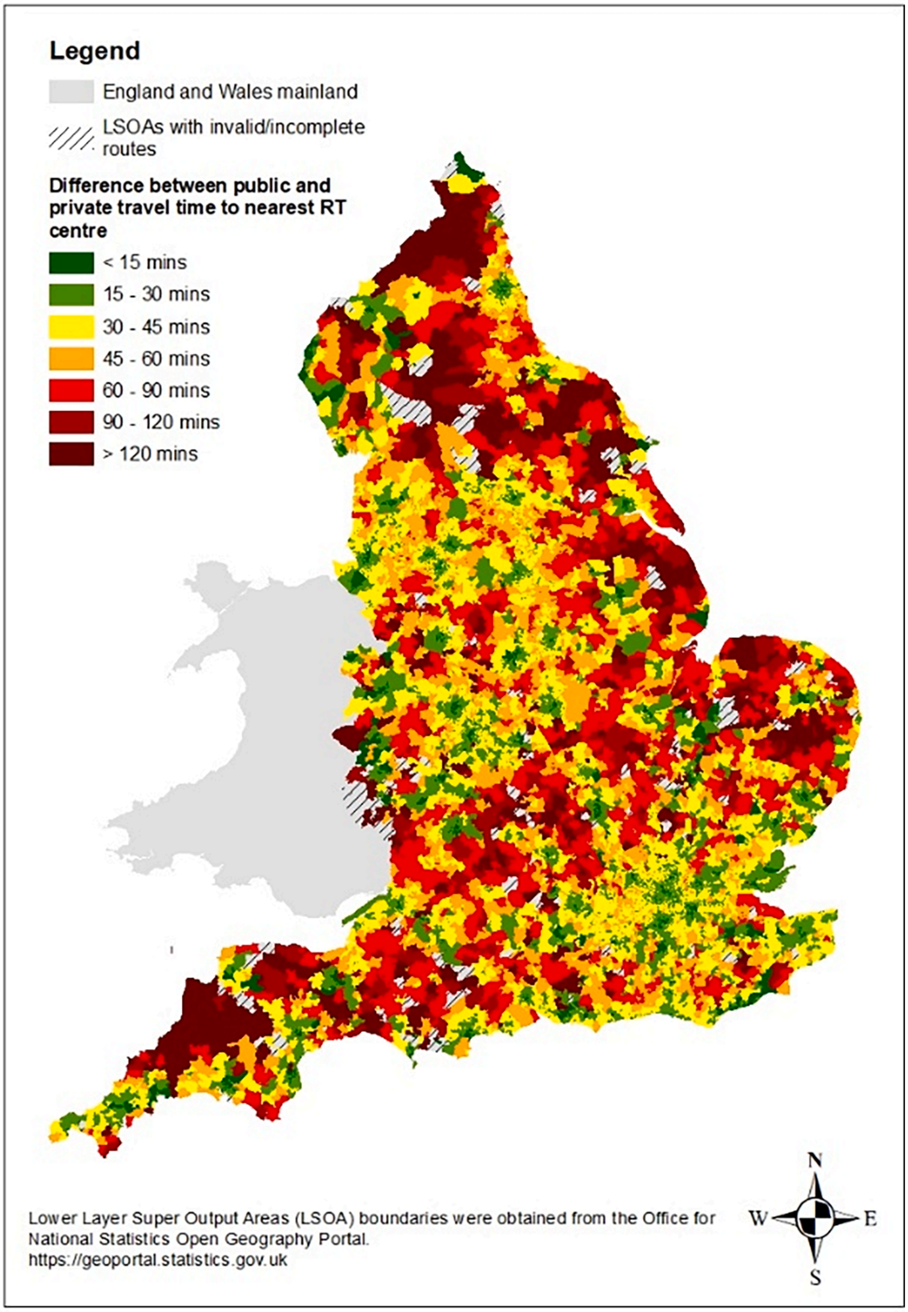

Fig. 2a. Time difference between travelling by public transport and private car to the nearest radiotherapy centre across England.

define the optimum location of specialist facilities when considering the geo-location of existing services, disease burden and travel times [41].

Whilst opening new facilities has been one consideration, the dominant policy for cancer services to drive improvements in outcomes has been centralisation of services to fewer specialist hospitals [42]. To inform this, we would recommend the use of quantitative health service planning tools that have been developed to support centralisation strategies by member states and through the EU Cancer Mission by estimating the expected impact of closing cancer units on travel burden, equity and outcomes [43,44].

Rather than centralisation of radiotherapy services, opportunities for increasing capacity (with new satellite radiation facilities) could be aligned to increasing quality through networked models of care delivery where technical aspects of the treatment pathway (contouring of target structures and creation of a physics plan) are centralised and treatment given more locally [45,46].

The strengths of this population-based study include the large number of patients included which underlines the representativeness of our results for a state-funded health service, and the high level of accuracy and completeness of most of the routinely collected data items. Our analytical approach used average day-time drive times when a patient was expected to have an appointment. This kind of analyses is considered superior to using straight-line distances. However, we acknowledge that drive times are variable depending on the time of day, which may affect patients' decision making. In addition, studies have demonstrated that GIS software can under-estimate travel times compared to that reported by patients themselves and these differences were greater for particular ethnic groups [47]. There are also limitations of the data. A total of 264 LSOAs (0.8 % out of 32,843) in England did not have any valid public transport to hospitals. 168 of these areas were

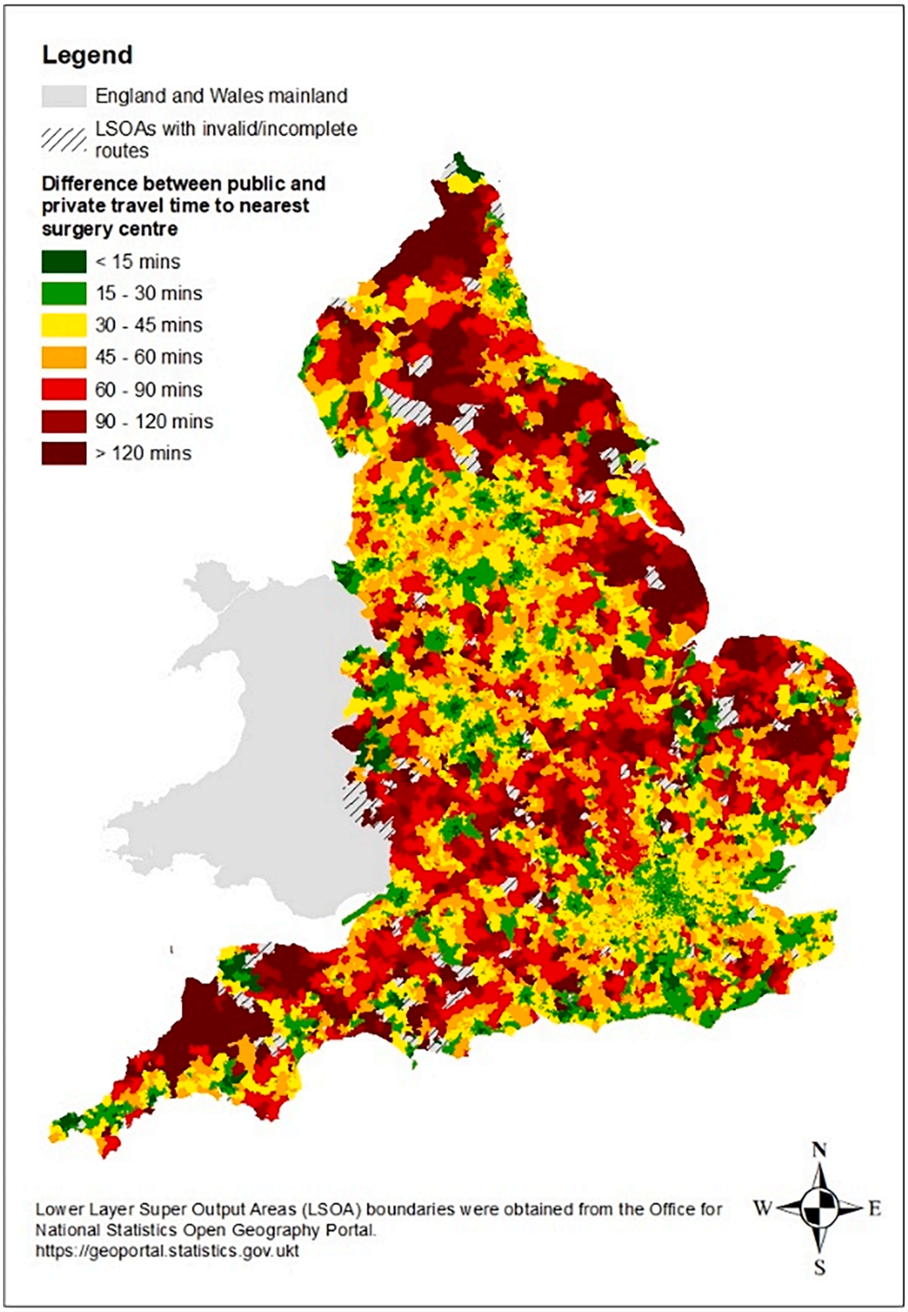

Fig. 2b. Time difference between travelling by public transport and private car to the nearest surgery centre across England.

rural towns and villages, whilst 96 were urban cities and towns. Patients living in these areas were not included in the analyses of public transport time which is likely to have resulted in an under-estimate of the overall travel time burden for those reliant on public transport.

In the study we used LSOAs to represent the patient's geographical location as postcodes are not available in the secondary datasets due to high sensitivity of this information. The centroids of LSOAs typically represent the most densely populated location point and are used as standard for these analyses. The use of LSOAs instead of postcodes will have added "noise" to the determination of travel times, and likely attenuated the observed relationships.

Furthermore, the public transport times used in this analysis are likely to under-estimate the actual time for patients to travel as they account for time in transit but do not consider time needed to walk to a station or bus stop nor to the final destination. We also do not include the gap between the transport timetables and the appointment time which is important for areas where there is only one bus service in the morning or afternoon and in reality would mean that public transport use is impossible. In some countries, patients are eligible for free hospital transport if they are from very low-income groups or have a disability or difficulty with mobility which offers protection against the widening of access disparities [48,49]. However, many remain ineligible and have to bear the cost of transport and time off work which can be a cause of financial distress [50]. Our datasets does not contain information on patient's actual travel mode. We therefore could not take into account of patient preference and had to analyse travel time by private car and public transport separately.

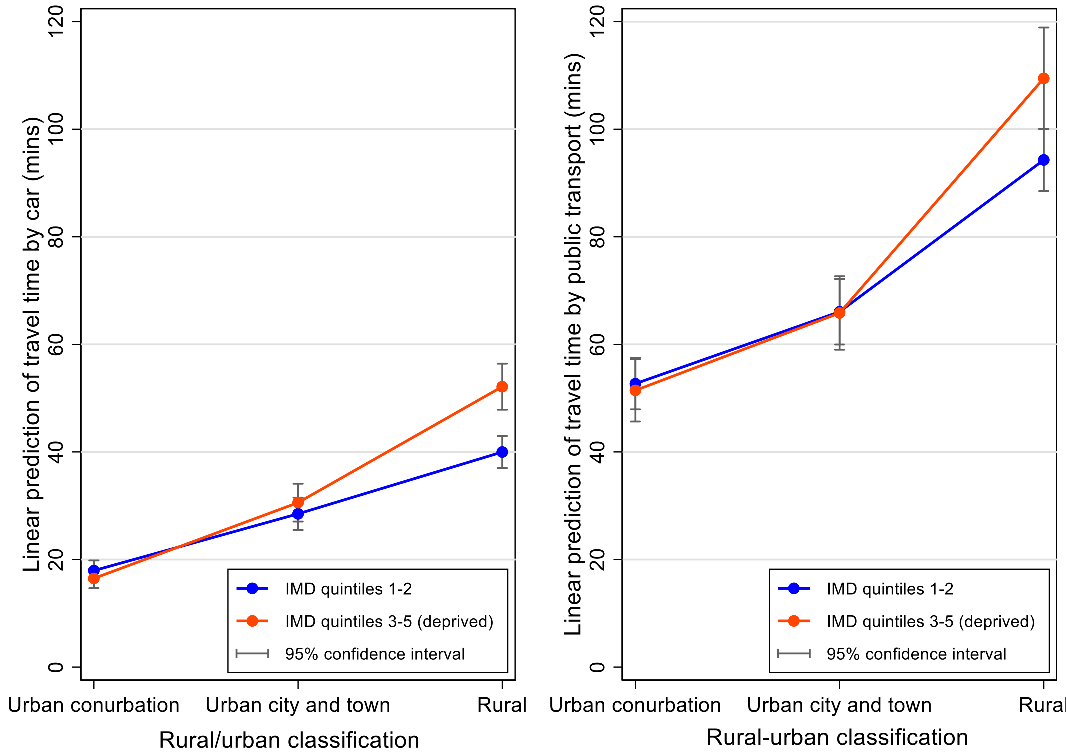

Fig. 3. Predicted travel time to radiotherapy centres taking into account the interaction effect between rurality of residence and socioeconomic status.

Conclusion

This study analysing travel times for patients receiving radiotherapy or surgery for prostate cancer found that patients reliant on public transport have travel times that are on average twice as long as those that have access to a car, particularly in rural areas. These travel time disparities related to rurality and were even greater for patients from more socioeconomically deprived areas. Without adequate provision of hospital transport and accommodation or due strategic consideration for how services are geo-located to optimise access, the configuration of cancer services by countries risks impacting on the utilisation of essential cancer treatment services and the widening of inequalities in outcomes.

Funding

National Institute for Health Research: NIHR300599.

Data availability statement

This study was based on English national cancer registry data. We do not own these data and hence are not permitted to share them in the original form. The data are available from the Office for Data Release at Public Health England. For access, please email odr@phe.gov.uk.

CRediT authorship contribution statement

Lu Han: Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Richard Sullivan:** Conceptualization, Writing – review & editing. **Alison Tree:** Writing – review & editing. **Daniel Lewis:** Methodology, Visualization. **Pat Price:** Writing – review & editing. **Vijay Sangar:** Writing – review & editing. **Jan van der Meulen:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Ajay Aggarwal:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This report is independent research supported by the National Institute for Health Research (NIHR Advanced Fellowship, Dr Ajay Aggarwal, NIHR300599). The views expressed in this publication are those of the author(s) and not necessarily those of the NHS, the National Institute for Health Research or the Department of Health and Social Care. 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 Cancer Registration and Analysis Service, which is part of Public Health England (PHE). Access to the data was facilitated by the PHE Office for Data Release. Alison Tree is supported by a Cancer Research UK Radiation Research Centre of Excellence at The Institute of Cancer Research and The Royal Marsden NHS Foundation Trust (grant ref: A28724) and a Cancer Research UK Programme Grant (ref: C33589/A28284). Alison Tree acknowledges NHS funding to the NIHR Biomedical Research Centre at The Royal Marsden and The Institute of Cancer Research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.radonc.2024.110092.

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