Health service planning to assess the expected impact of centralising specialist cancer services on travel times, equity, and outcomes: a national population-based modelling study

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Summary

Background Centralisation of specialist cancer services is occurring in many countries, often without evaluating the potential impact before implementation. We developed a health service planning model that can estimate the expected impacts of different centralisation scenarios on travel time, equity in access to services, patient outcomes, and hospital workload, using rectal cancer surgery as an example.

Methods For this population-based modelling study, we used routinely collected individual patient-level data from the National Cancer Registration and Analysis Service (NCRAS) and linked to the NHS Hospital Episode Statistics (HES) database for 11 888 patients who had been diagnosed with rectal cancer between April 1, 2016, and Dec 31, 2018, and who subsequently underwent a major rectal cancer resection in 163 National Health Service (NHS) hospitals providing rectal cancer surgery in England. Five centralisation scenarios were considered: closure of lower-volume centres (scenario A); closure of non-comprehensive cancer centres (scenario B); closure of centres with a net loss of patients to other centres (scenario C); closure of centres meeting all three criteria in scenarios A, B, and C (scenario D); and closure of centres with high readmission rates (scenario E). We used conditional logistic regression to predict probabilities of affected patients moving to each of the remaining centres and the expected changes in travel time, multilevel logistic regression to predict 30-day emergency readmission rates, and linear regression to analyse associations between the expected extra travel time for patients whose centre is closed and five patient characteristics, including age, sex, socioeconomic deprivation, comorbidity, and rurality of the patients' residential areas (rural, urban [non-London], or London). We also quantified additional workload, defined as the number of extra patients reallocated to remaining centres.

Findings Of the 11 888 patients, 4130 (34·7%) were women, 5249 (44·2%) were aged 70 years and older, and 5005 (42·1%) had at least one comorbidity. Scenario A resulted in closures of 43 (26%) of the 163 rectal cancer surgery centres, affecting 1599 (13·5%) patients; scenario B resulted in closures of 112 (69%) centres, affecting 7029 (59·1%) patients; scenario C resulted in closures of 56 (34%) centres, affecting 3142 (26·4%) patients; scenario D resulted in closures of 24 (15%) centres, affecting 874 (7·4%) patients; and scenario E resulted in closures of 16 (10%) centres, affecting 1000 (8·4%) patients. For each scenario, there was at least a two-times increase in predicted travel time for re-allocated patients with a mean increase in travel time of 23 min; however, the extra travel time did not disproportionately affect vulnerable patient groups. All scenarios resulted in significant reductions in 30-day readmission rates (range 4–48%). Three hospitals in scenario A, 41 hospitals in in scenario B, 13 hospitals in scenario C, no hospitals in scenario D, and two hospitals in scenario E had to manage at least 20 extra patients annually.

Interpretation This health service planning model can be used to to guide complex decisions about the closure of centres and inform mitigation strategies. The approach could be applied across different country or regional health-care systems for patients with cancer and other complex health conditons.

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See Comment page 1120

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Introduction

The centralisation of complex cancer surgery into high-volume centres is occurring in many high-income and middle-income countries, driven by evidence that patients have better outcomes if they are treated by specialised and experienced teams at centres doing a large number of surgical procedures.[1–3] However, a consequence of the centralisation of services is that patients might need to travel further for treatment, which can negatively affect access to such services, especially for those patients less able to travel.[4–8] This fine balance between travel burden, equitable access to services, and outcomes means that it is important to estimate the expected impact of service centralisation before implementation.[7–10]

An established empirical template to define the optimal configuration of cancer services is currently lacking. Without such health service planning tools, decisions

Research in context

Evidence before this study

Centralisation of complex surgical and medical services is occurring in many countries, with the aim of improving the quality and efficiency of care. However, there is no generally accepted approach that can be used to estimate the expected impact of centralisation of specialist services on travel time, equity in access to health-care services, patient outcomes, and hospital workload. We searched MEDLINE for full-text articles published between Jan 1, 1990, and Feb 28, 2022, to assess the different approaches that have been used to estimate the expected impact of centralisation to inform the optimal reconfiguration of health services. The search was restricted to English language publications. Search terms included "centralization OR centralisation" AND ("predict*" OR "simul*" OR "model") AND ("travel burden" OR "equity" OR "travel time" OR "patient outcome"). We found only a few studies that had attempted to estimate the expected impact of centralisation scenarios before implementation. Studies based on existing datasets typically used a distance-minimisation approach, whereby patients of closed centres are allocated to their nearest remaining centre. This approach does not acknowledge that there are other factors than travel time that could determine where patients choose to have their treatment. We did not identify any studies that modelled the expected impact of centralisation on patient outcomes after cancer treatment.

Added value of this study

In this population-based modelling study we used linked national clinical and administrative datasets for almost 12 000 patients who had major rectal cancer surgery between 2016 and 2018 in the National Health Service (NHS) in England to model the expected impact of five centralisation scenarios on the travel burden, equity in access to health-care services, and outcomes of patients affected by closures and the expected increases in workload in centres that remain open. This study demonstrates an innovative approach to establishing the impact of centralising complex treatment services for patients with cancer or other health conditions. The health service planning model used in this study provides explicit estimates of the expected consequences of the different centralisation scenarios that can guide often controversial and sensitive decisions about the closure of centres and help to inform mitigation strategies as well as transparently define and prioritise criteria for centralisation. The modelling approach is adaptable according to the data available and can be applied to other health-care system contexts.

Implications of all the available evidence

Centralisation of cancer services is designed to improve outcomes and the efficiency of the service, but can have negative consequences on equity in access to services, travel burden, and hospital workload. By using routinely collected clinical and administrative data, this study adds to the contemporary literature in providing a transparent framework to guide policymakers on the trade-offs resulting from different models of centralisation to inform optimum cancer service design.

about the closure of cancer centres might instead be driven by political reasons rather than by a transparent assessment of the expected consequences of centralisation of services for patients and providers.[11,12] A recent example from prostate cancer surgery in the National Health Service (NHS) in England suggested that decisions to close or merge surgery centres were influenced by bottom-up drivers of service change, such as patient choice and competition between surgical providers, rather than improved population equity and outcomes.[13]

We developed an innovative health service planning model based on analyses of linked national clinical and administrative hospital datasets that can be applied in all resource settings. Using rectal cancer surgery in the NHS in England as an example, we aimed to demonstrate how this model can be used to estimate the expected impact of five centralisation scenarios on travel time, equity in access to health services, patient outcomes, and hospital workload. This clinical example was chosen because in many high-income and middle-income countries there is a focus on the potential benefits of centralising rectal cancer surgery centres to fewer high-volume centres, based on evidence supporting a volume–outcome association.[14,15]

Methods

Data sources and study population

For this population-based modelling study, we obtained individual patient-level data for all patients who had been diagnosed with rectal cancer between April 1, 2016, and Dec 31, 2018 (33 months), and subsequently underwent a major rectal cancer resection in the NHS in England. Data were retrieved from the National Cancer Registration and Analysis Service (NCRAS) and linked to the NHS Hospital Episode Statistics (HES) database.[16,17]

Patients were eligible for inclusion if they had undergone elective non-emergency rectal cancer surgery, had been treated in one of the 163 pre-identified hospital centres that routinely perform rectal cancer surgery, and had not been diagnosed with metastatic disease (M1) at the time of surgery. Patients who had undergone surgery in the private sector were excluded from this analysis (<5% of eligible patients).

HES provided information on patient-level characteristics, including age, sex, the number of comorbidities according to the Royal College of Surgeons' Charlson Comorbidity Index,[18] socioeconomic deprivation expressed in terms of quintiles of the national distribution of the Index of Multiple Deprivation (IMD) in 2015,[19] the

treating hospital, date of surgery, the type of major resection (eg, anterior resection), and the occurrence of emergency readmissions within 30 days of the date of discharge following a major rectal resection. The IMD provides an area-based measure of socioeconomic deprivation. Less deprived patients were defined as those living in areas with an IMD in the lowest two quintiles and more deprived patients were defined as those living in the highest three quintiles of the national distribution. Rectal cancer surgery procedure information was coded according to the Office of Population Censuses and Surveys Classification of Surgical Operations and Procedures, 4th Revision (OPCS-4).[20] The rurality of the area of residence was captured as rural, urban (non-London), or London.[21] The cancer registry data provided information on cancer stage.

Patients' residential location was represented by the population-weighted centroids of their Lower-layer Super Output Areas (LSOAs). There are 32 844 LSOAs in England, defined as small areas that typically include 1500 residents or 650 households.[22] A geographical information system (ESRI ArcGIS; Redlands, CA, USA) was used to determine average daytime travel times by private car between the patients' residential locations and the 163 NHS hospital sites that provide rectal cancer surgery.

Centralisation scenarios

For the purpose of this study, we created five centralisation scenarios based on current clinical and policy discussions around quality improvement, patient experience, and efficient use of resources in the NHS in England.[23] These scenarios were designed to show the range of different centralisation scenarios that can be tested within the model and their implications on the number of patients and hospitals affected, travel burden, equity, outcomes, and hospital capacity, so that they can be used to inform policy. The scenarios were not mutually exclusive (ie, a centre might meet criteria for more than one scenario). The centres expected to be closed in each scenario were mapped to show their geographical location with ESRI ArcGIS software (figure 1).

In scenario A (closure of lower-volume centres), low-volume centres doing fewer than 20 procedures per year are closed. We identified centres on the basis of the distribution of actual procedure volumes from Jan 1, 2017, to Dec 31, 2018, according to HES. In this scenario, 43 (26%) of the 163 hospitals would close their rectal surgery centres. This scenario follows evidence supporting improvements in perioperative and postoperative outcomes when surgery is performed in high-volume relative to low-volume centres.[24]

In scenario B (closure of non-comprehensive cancer centres), surgical treatment is provided only by comprehensive cancer centres, which are defined in this analysis as hospitals that offer surgery, radiotherapy, and systemic therapies onsite. From the patient perspective this situation is desirable because all main treatment modalities, including neoadjuvant rectal cancer treatment, are available in one hospital without the need for further travel. In this scenario, 112 (69%) of 163 non-comprehensive centres would be closed.

In scenario C (closure of centres with a net loss of patients to other centres), surgical centres that are experiencing a net loss of patients from their catchment area to surgical centres in other hospitals are closed.

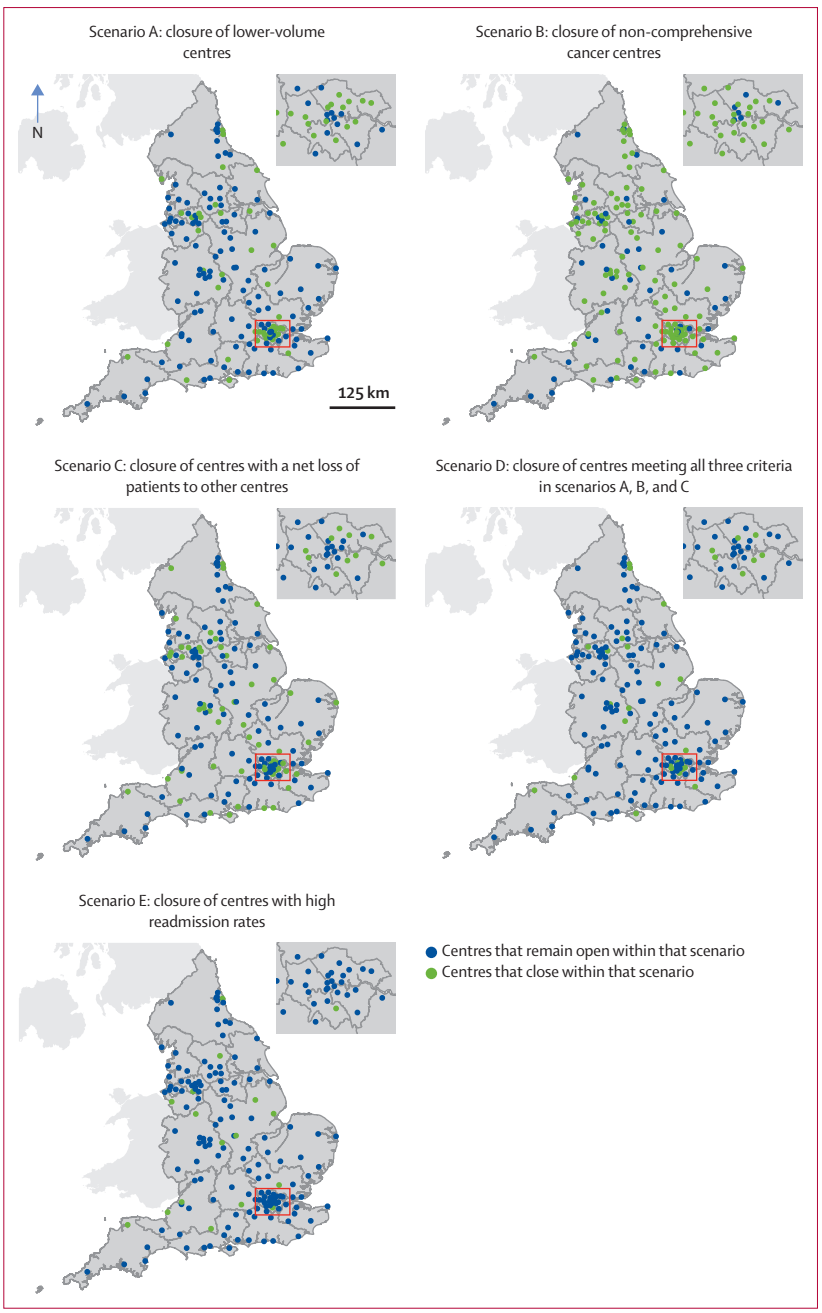

Figure 1: **Location of the rectal cancer surgery centres affected by each of the five centralisation scenarios**
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See Online for appendix

Centralisation in this scenario would respond to the pre-existing flows of patients to particular hospitals, which are affected by choices that patients make. Hospitals with a net loss of patients were identified with HES data for patients with rectal cancer treated between April 1, 2016, and Dec 31, 2018. A centre was identified as having a net loss of patients if the difference between the number of leavers (ie, patients for whom that centre was nearest but who had their treatment at an NHS centre further away) and arrivers (ie, patients for whom another centre was nearest but who had their surgery at that centre) was statistically significant based on the conditional method for testing a difference between two Poisson means.[25,26] The net gain or loss was aggregrated over the 3-year time period. In this scenario, 56 (34%) of 163 centres had a net loss and would be closed.

In scenario D (closure of centres meeting all three criteria in scenarios A, B, and C), surgical centres that meet all three criteria—they are low volume, they are non-comprehensive, and they experience a net loss of patients to other centres—are closed. This scenario prioritises the closure of centres that meet all three criteria rather than any one of the three criteria, which results in a smaller and, therefore, a potentially more realistic number of centres closing (24 [15%] of 163).

In scenario E (closure of centres with high readmission rates), closures are guided by patient outcomes. In this scenario, the 10% of units with the highest 30-day readmission rates following rectal cancer surgery in the NHS in England (ie, 16 [10%] of 163) would be closed. Hospital readmission rates following major cancer surgery are an established surgical performance indicator and currently publicly reported in the NHS in England.[27] The adjusted 30-day emergency readmission rates following major rectal cancer surgery were estimated with linked patient-level cancer registry and HES data in patients who had a major rectal cancer resection and were diagnosed between April 1, 2016, and Dec 31, 2018.

Reallocation approach and estimating the impact on travel time

In our model, patients affected by each centralisation scenario (ie, the hospital where they are treated is planned to close) were reallocated to alternative hospitals by use of two main methods.[9] The first approach reallocated patients affected by the closure to their nearest available hospital following its closure, and was termed the distance minimisation approach. Expected changes in travel time were estimated as the difference between travel times to the actual centre used before centralisation and the nearest available hospital following its closure.

The second approach reallocated patients on the basis of choice modelling by use of a conditional logit regression model.[26,28] The model estimated the probabilities that patients would receive treatment at a particular hospital according to how far away they lived from the centre (measured as travel time), the characteristics of the hospital (see appendix p 1 for the full list), and the patients' characteristics (age, sex, socioeconomic deprivation, comorbidity, and rurality of the patients' residential areas—ie, rural, urban [non-London], or London). The model used actual travel patterns of patients, and considered differences in patients' willingness to travel according to their unique set of characteristics. For example, based on previous empirical research,[26] younger and fitter patients are more likely to travel to more distant hospitals than elderly patients, and so the probabilities of patients receiving treatment at a particular hospital are different depending on their unique demographic profile, which we accounted for (appendix pp 1–3).

Using this regression model, for each individual patient affected by centre closures we estimated the probabilities of receiving surgery in each of the remaining centres. These probabilities reflect the relative importance of the remaining cancer centres to the patient. In most cases, there will usually be two or three hospitals with the highest probabilities, with the rest of the eligible centres having very low probabilities as the probabilities sum to 100%.

We estimated the expected changes in travel times following reallocation as the difference between the actual travel time and the weighted average of travel times to remaining centres after centralisation using the probabilities predicted by the regression model of receiving treatment at each of the hospitals as weights (see appendix p 2 for validation of our prediction model).

Impact on equity in access

Patients from different sociodemographic groups are potentially more likely to live in particular parts of the country, which in turn can have different levels of accessibility to surgical care and high-quality services. We aimed to establish whether the closure of centres in each scenario would result in disproportionate travel time impacts on particular demographic groups. For example, if patients in more deprived groups also live closer to poorly performing centres, closures of these centres would result in a greater travel burden for this group.

To estimate the equity implications of each centralisation scenario, we used linear regression models to evaluate the association between the expected extra travel time for patients whose centre is closed and five patient characteristics. This included age (categorised as <60, 60–69, 70–79, or ≥80 years), sex (male *vs* female), socioeconomic deprivation (higher socioeconomic status, defined as IMD quintiles 1 and 2, *vs* lower socioeconomic status, defined as IMD quintiles 3 to 5), comorbidities (no comorbidity *vs* one or more comorbidities), and rurality of the patients' residential areas (rural, urban [non-London], or London) to ascertain whether the additional travel time for patients affected by the reallocation scenario is higher or lower for specific patient groups compared with the reference patient.

The reference patient was defined according to the characteristics that a priori would be considered to

confer greater access to health care within a category (eg, a patient with no comorbidity compared with a patient with comorbidity). Where it was not possible to determine an a-priori favourable category (eg, urban or rural residence), we used the category with the largest number of patients as the reference category. As a result, the reference patient was a male patient, younger than 60 years without any comorbidities, living in less deprived areas (ie, the lowest two IMD quintiles), and residing in an urban area outside London. With this approach, we were able to establish the difference in travel time burden in patients with a comorbidity compared with those without them, and other similar comparisons based on patient characteristics.

Impact on health outcomes

For patients affected by a specific centralisation scenario, we investigated whether or not the closure of rectal cancer surgery centres and reallocation to an alternative hospital resulted in a higher or lower total number of hospital readmissions across the reallocated patients. To estimate the expected change in the readmission rate, we applied a multilevel logistic regression model with random hospital intercepts to quantify the association between patient-level risk factors and 30-day emergency readmission following major rectal cancer surgery. Patient-level risk factors were age (at the time of surgery), sex, socioeconomic deprivation according to IMD quintiles, number of comorbidities (as described above), pre-treatment T stage, and year of surgery (further details, including multiple imputation of missing T stage and validation of the model, are provided in appendix pp 6–7).

The results of this model were then used to predict the expected risk of a readmission following surgery for patients who would have been reallocated to

	Total patient group: 163 centres (11 888 patients)	Scenario A: 43 centres closing (1599 patients moving to another centre)	Scenario B: 112 centres closing (7029 patients moving to another centre)	Scenario C: 56 centres closing (3142 patients moving to another centre)	Scenario D: 24 centres closing (874 patients moving to another centre)	Scenario E: 16 centres closing (1000 patients moving to another centre)
Age, years*						
<60	2892 (24·3%)	393 (24·6%)	1684 (24·0%)	716 (22·8%)	222 (25·4%)	247 (24·7%)
60–69	3747 (31·5%)	500 (31·3%)	2220 (31·6%)	994 (31·6%)	275 (31·5%)	290 (29·0%)
70–79	3756 (31·6%)	478 (29·9%)	2227 (31·7%)	1026 (32·7%)	259 (29·6%)	320 (32·0%)
≥80	1493 (12·6%)	228 (14·3%)	898 (12·8%)	406 (12·9%)	118 (13·5%)	143 (14·3%)
Sex						
Male	7758 (65·3%)	1053 (65·9%)	4611 (65·6%)	2095 (66·7%)	586 (67·1%)	641 (64·1%)
Female	4130 (34·7%)	546 (34·2%)	2418 (34·4%)	1047 (33·3%)	288 (33·0%)	359 (35·9%)
Socioeconomic deprivation (IMD)						
First quintile (least deprived)	2743 (23·1%)	316 (19·8%)	1532 (21·8%)	571 (18·2%)	128 (14·7%)	268 (26·8%)
Second quintile	2706 (22·8%)	351 (22·0%)	1595 (22·7%)	698 (22·2%)	182 (20·8%)	250 (25·0%)
Third quintile	2537 (21·3%)	354 (22·1%)	1493 (21·2%)	641 (20·4%)	203 (23·2%)	200 (20·0%)
Fourth quintile	2153 (18·1%)	339 (21·2%)	1311 (18·7%)	655 (20·9%)	214 (24·5%)	164 (16·4%)
Fifth quintile (most deprived)	1749 (14·7%)	239 (15·0%)	1098 (15·6%)	577 (18·4%)	147 (16·8%)	118 (11·8%)
Rurality						
Rural	2791 (23·5%)	306 (19·1%)	1466 (20·9%)	642 (20·4%)	165 (18·9%)	270 (27·0%)
Urban (non-London)	7999 (67·3%)	848 (53·0%)	4720 (67·2%)	2204 (70·2%)	501 (57·3%)	686 (68·6%)
London	1098 (9·2%)	445 (27·8%)	843 (12·0%)	296 (9·4%)	208 (23·8%)	44 (4·4%)
Number of comorbidities						
0	6883 (57·9%)	892 (55·8%)	4003 (57·0%)	1822 (58·0%)	489 (56·0%)	600 (60·0%)
1	3377 (28·4%)	491 (30·7%)	2044 (29·1%)	887 (28·2%)	273 (31·2%)	268 (26·8%)
≥2	1628 (13·7%)	216 (13·5%)	982 (14·0%)	433 (13·8%)	112 (12·8%)	132 (13·2%)
Pretreatment stage T						
T1 and T2	3446 (29·0%)	485 (30·3%)	2134 (30·4%)	940 (29·9%)	269 (30·8%)	297 (29·7%)
T3 and T4	6732 (56·6%)	929 (58·1%)	3935 (56·0%)	1815 (57·8%)	504 (57·7%)	586 (58·6%)
Missing T stage information	1710 (14·4%)	185 (11·6%)	960 (13·7%)	387 (12·3%)	101 (11·6%)	117 (11·7%)
Travel time, min						
Mean (SD)	19·3 (16·4)	15·4 (13·8)	17·3 (14·2)	15·3 (14·3)	15·0 (14·6)	19·4 (16·3)
Median (IQR)	14·2 (8·3–25·1)	10·7 (6·4–20·0)	13·0 (7·8–22·1)	10·5 (6·8–18·1)	9·8 (6·3–17·9)	13·6 (8·5–25·0)

Data are n (%), mean (SD), or median (IQR). IMD=Index of Multiple Deprivation. Scenario A: closure of lower-volume centres. Scenario B: closure of non-comprehensive cancer centres. Scenario C: closure of centres with a net loss of patients to other centres. Scenario D: closure of centres meeting all three criteria in scenarios A, B, and C. Scenario E: closure of centres with high readmission rates. *Age at the time of surgery.

Table 1: **Patients demographic characteristics in centres that closed according to each centralisation scenario**

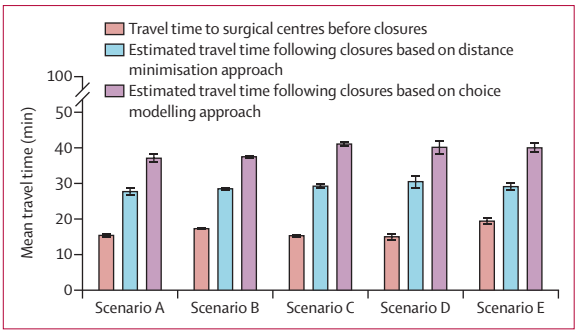

Figure 2: **Mean travel time for patients affected by centre closures, according to the five centralisation scenarios and two reallocation methods**
Error bars denote 95% CIs.

alternative centres in each scenario. Using the distance-minimisation reallocation approach, the patient-level risks of readmission were predicted by use of the centre effect (eg, predicted intercept from the multilevel logit model) of the nearest available centre and the patient-level characteristics (which remained unchanged).

For reallocation based on choice modelling, we first estimated for affected patients the risk of readmission in each of the remaining surgical centres that remained open. The expected patient-level readmission rates were then estimated as the weighted average of the readmissions risk with the probabilities (predicted by the choice model) of receiving treatment at each of the remaining hospitals as weights.

We subsequently assessed the impact of centralisation on patient outcome by comparing the expected number of readmissions among patients who were reallocated according to a specific centralisation scenario against the actual observed number of readmissions in these patients pre-centralisation.

Impact on workload in the remaining hospitals

We compared the extra workload in the remaining centres following reallocation against the current capacity of these hospitals to predict whether or not a specific centralisation scenario would require substantial additional capacity to be created to manage the expected increase in patient numbers. We identified those centres that would receive between five and nine extra patients, between ten and 19 extra patients, and 20 or more extra patients, for each of the five centralisation scenarios. The extra patient numbers to alternative hospitals in each scenario was calculated separately with the two reallocation approaches. We also estimated the proportional increase in the expected number of procedures at each hospital per year compared with the baseline number of procedures done.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

The final sample comprised 11888 patients living in England who were treated in 163 NHS hospitals providing rectal cancer surgery. 1960 patients were not eligible for inclusion in the analysis (appendix p 8). Of the 11888 patients, 4130 (34·7%) were female, 5249 (44·2%) were aged 70 years and older, and 5005 (42·1%) had at least one comorbidity. 2791 (23·5%) patients lived in rural areas and 6439 (54·2%) lived in areas of higher socioeconomic deprivation (IMD quintiles 3–5; table 1). If all patients had travelled by car, their mean expected journey time to hospital would have been 19·3 min (SD 16·4), median 14·2 min (IQR 8·3–25·1).

Each scenario would result in considerable differences in the number of centres closed and in the number of patients affected (table 1) and would result in a substantial increase in the travel time for patients affected by closures (figure 2; appendix p 9). However, there was no clear association between the number of centres closed and the expected extra travel time for the reallocated patients. For example, across the scenarios, closures would result in patients having to travel on average an extra 20 min in both scenario B (closure of 112 non-comprehensive cancer centres) and scenario E (closure of 16 centres with high readmissions), based on the choice modelling approach. The expected increase in travel time for those affected by centralisation was also consistently less with the distance minimisation approach (the mean additional travel time across the five scenarios was approximately 13 min) compared to the choice modelling approach (the mean additional travel time across the five scenarios was 23 min).

From an equity perspective, the average impact of the five centralisation scenarios (using the choice modelling approach) on the extra travel time for specific patient groups (based on patient characteristics) relative to the reference patient is summarised in the appendix (pp 10–11). Patients living in the London metropolitan area had a consistently lower expected extra travel time than patients living in urban areas, due to the higher density of hospital provision in Greater London compared with other urban areas. There was no clear evidence that the expected extra travel time was higher in patients with comorbidities than in those without comorbidities, in patients living in more socioeconomically deprived areas than in those living in less deprived areas, or older patients. The results based on the distance minisation model followed a similar pattern and are presented in the appendix (p 12), although older patients (aged ≥80 years) had higher extra travel time than younger patients (aged <60 years).

In patients who would have been affected by a centralisation scenario, we compared the observed number of 30-day readmissions with the 30-day readmissions expected if patients went to alternative rectal cancer surgery centres based on the two reallocation approaches (table 2). Apart from scenario E (closure of centres with high readmission rates) where, as expected, there was a

	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Number of patients moving to alternative centres	1599	7029	3142	874	1000
Number of 30-day emergency readmissions observed in patients affected by closure scenario	234	1024	475	142	257
Number of expected readmissions based on distance minimisation approach (95% CI)*	222·3 (219·9–224·7)	970·1 (965·5–974·7)	442·1 (438·6–445·6)	123·6 (121·9–125·4)	134·2 (132·6–135·8)
Number of expected readmissions based on choice modelling approach (95% CI)*	224·9 (222·9–226·9)	975·2 (971·1–979·4)	441·8 (438·8–444·8)	123·5 (122·0–124·9)	134·1 (132·6–135·6)

Scenario A: closure of lower-volume centres. Scenario B: closure of non-comprehensive cancer centres. Scenario C: closure of centres with a net loss of patients to other centres. Scenario D: closure of centres meeting all three criteria in scenarios A, B, and C. Scenario E: closure of centres with high readmission rates. *95% CIs are based on variations of predicted probability of readmission at a patient level, and do not include uncertainty in the estimation of readmission risk.

Table 2: **Expected number of 30-day emergency readmissions according to the five centralisation scenarios and two reallocation methods in patients afffected by closures**

	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Number of centres closed	43 (26%)	112 (69%)	56 (34%)	24 (15%)	16 (10%)
Number of patients affected by closures	1599 (13·5%)	7029 (59·1%)	3142 (26·4%)	874 (7·4%)	1000 (8·4%)
Expected additional travel time in affected patients*, min	21·7 (20·4–23·0)	20·2 (19·7–20·7)	26·1 (25·3–26·9)	25·1 (23·2–27·1)	20·6 (19·0–22·2)
Equity impact on specific demographic groups	None	None	None	None	None
Extra workload in remaining centres (number of centres performing 20 or more extra surgeries per year)	3 centres	41 centres	13 centres	0 centres	2 centres
Extra workload in remaining centres (number of centres expected to perform greater than 50% extra surgeries per year)	7 centres	41 centres	34 centres	3 centres	6 centres
Patient outcome, changes in 30-day readmission rates	–4%	–5%	–7%	–13%	–48%

Scenario A: closure of lower-volume centres. Scenario B: closure of non-comprehensive cancer centres. Scenario C: closure of centres with a net loss of patients to other centres. Scenario D: closure of centres meeting all three criteria in scenarios A, B, and C. Scenario E: closure of centres with high readmission rates. Results are based on the choice modelling reallocation approach. *Data shown are means (95% CIs).

Table 3: **Summary table of trade-offs for each centralisation scenario to inform health service planning**

substantial reduction (48%) in readmissions expected from centralisation, the differences across the other scenarios were small.

From a workload perspective, the number of remaining centres to which patients would be reallocated and the expected number of extra patients each of these centres will need to treat per year, both in absolute terms but also relative to the number of procedures they perform annually, is presented in the appendix (pp 13–14). Substantial variation was observed according to the five centralisation scenarios and the two reallocation approaches.

The expected increase in the number of patients at each individual surgical centre following reallocation relative to the number of patients currently treated is shown in the appendix (pp 15–19). In scenarios A (closure of lower-volume centres), D (closure of centres meeting all three criteria in scenarios A, B, and C), and E (closure of centres with high readmission rates), for the majority of centres receiving patients from centres that close, the reallocated patients only represented a small proportion of the patients who would need to receive treatment at the centre. However, in scenario B (closure of non-comprehensive cancer centres), 7029 patients would be affected and in scenario C (closure of centres with a net loss of patients to other centres) 3142 patients would be affected. As a result, many more rectal cancer surgery centres would have to increase their capacity substantially to manage the expected increased arrival of patients after centralisation.

The modelling results estimating the association between the five centralisation scenarios and travel time, equity in access to services, patient outcomes, and workload are summarised in table 3, which provides an explicit cancer services planning tool.

Discussion

We developed an innovative health service planning model based on national clinical and administrative datasets to estimate the expected changes in travel time, equity in access to services, patient outcomes, and clinical workload after centralisation of rectal cancer surgery services. Five different centralisation scenarios in the NHS in England were evaluated to enable a robust and transparent evaluation of the trade-offs across these four key domains to inform the planning of national cancer services. Our model was developed by an international team and can be used in other countries or regions that have sought to define the impact or optimum approach to centralisation of specialist services in their

context with respect to population size, geography, and availability of services.[8,29–32] For example, the model can be applied to managed-care settings within health insurance or preferred-provider networks that enable patients to select a treatment provider at the point of referral.[33]

Multiple different centralisation options can be tested, according to the priorities and service structure of a given country, region, or insurer that is considering reconfiguration of its services. This would allow an informed discussion of the impact of different centralisation scenarios, ideally involving key policy stakeholders, clinicians, and patients before implementation.

Where centralisation might widen inequalities or where workforce capacity might be an issue, this type of pre-implementation impact assessment can facilitate the development of mitigating interventions. The use of national rather than regional or state-level cancer registration or administrative datasets also allows an exploration of possible differences in the impact for patients living in rural areas or in more densely populated urban areas. Another important feature of our proposed approach is that it allows an estimate of the number of people who are predicted to be affected by different centralisation scenarios, the specific hospitals most likely to be affected, as well as the extra time that patients are expected to travel, which is not necessarily commensurate with the numbers of centres closed.

The cancer service planning tool can be used for different types of common cancers or modalities of treatment, and has been used for considering the travel burden and equity implications of the centralisation of prostate cancer surgery.[9] However, the model will be less applicable to very rare cancer types for which few patients are treated annually or where the service is already highly centralised. It could also be applied to the planning of the location of advanced treatment modalities (eg, the location of proton therapy, MRI-guided linear accelerator, and chimeric antigen receptor [CAR] T-cell units).

In terms of oncological outcomes, we used 30-day readmission rates. However, the impact on other clinical outcome measures can easily be considered if there is evidence for substantial between-hospital differences, including margin status, rates of treatment-related adverse events, or relapse rates.[34] In the NHS, information about mortality is published for bowel and oesophageal cancer surgery, and our model could include this information to assess the impact of centralisation on these outcomes as an alternative or in addition to readmission rates.[27,35]

With respect to the implications of centralisation, other areas that can be included in future development of the model are the use of service delivery costs, such as with diagnosis-related group tariffs, to understand the economic consequences of centralisation as patients are reallocated.[3] Additionally, a more detailed understanding of workforce requirements and theatre capacity for individual hospitals could provide further granularity to the model. In the NHS in England, developing the model further to include parameters such as workforce and to assess the feasibility of the centralisation options would require discussions with the national body that is responsible for commissioning specialist cancer services.[36]

In our study we used a novel choice modelling approach to reallocate patients, which is likely to provide a more realistic picture of travel patterns following centralisation since it explicitly considers preferences reflecting patient characteristics and the attributes of available hospitals. In comparison, we demonstrated how the distance minimisation approach used in previous studies[8,10,29] risks underestimating the expected extra travel time after closures of particular centres and results in inaccurate forecasting of the capacity implications for centres that remain open.

We also explored the impact of closures according to particular patient characteristics. We found that the expected extra travel time for patients seemed to be higher for patients older than 80 years, and although this represented a small additional increase, it was significant when considered as a proportion of the overall expected increase in travel time. This finding emphasises the importance of this analysis because it can highlight circumstances where centralisation is likely to affect specific groups that are already experiencing access challenges to high-quality care, especially when other patient-related factors also play a part.[37–42]

Our model used drive times by car, but public transport times or geographical distance can be used instead. It is important to note that drive times by a private car reflect average conditions and drive times will vary according to the time of the day and day of the week, but the relative differences in drive times to nearby hospitals are likely to be relatively stable. In the real world, patients will use a range of methods of transport according to individual preferences, the quickest mode of transport to the hospital, as well as private car ownership. Data on the method of transport used are not currently available for patients travelling to NHS hospitals in England but can be included in the model in settings where this information is available. Although rates of private car ownership might be lower for patients from more socioeconomically deprived groups, patients in the NHS are eligible for free hospital transport if they are from low-income groups or have a disability or difficulty with mobility.[43]

A limitation of the study is that we were not able to verify the model by comparing the expected impact of centralisation estimated with this health service planning model with observed changes in travel time, access to services, outcomes, and hospital workload, since none of the hospitals has closed. Further analyses across different time periods and in different settings would be the next step to confirm the robustness of this model. We have provided evidence for the predictive power of the model, in terms of estimating the probabilities of where patients

would be likely to receive treatment if their nearest centre was to close (using the choice model), as well as the estimation of readmission rates for patients reallocated to other centres. Another limitation of this study is that we did not provide uncertainty estimates for the expected increase in the number of patients treated at each centre following centralisation. This estimation will be a priority for future work. Finally, although changes in clinical practice might affect patterns of patient referral, this remained stable for each year of the analysis.

The datasets we used in this analysis provide detailed information about patients' characteristics, treatments, and outcomes. However, the modelling approach can be adapted according to the patient-level information that is available or the design of the service (ie, the number of centres and their location) in a particular country or region. The trade-offs also need to be considered in the context of the size of a country and the pre-existing service provision. For instance, in smaller countries, absolute travel time differences will be less than those in larger countries but even so, understanding the implications of centralisation on hospital workload given the expected shift in patient volumes following closures, as well as the implications on equity and outcomes, remains highly relevant. We deliberately chose relatively extreme scenarios, not as explicit recommendations, but to demonstrate as a proof of concept how the model can estimate the impacts in these four key domains to inform policy.

In summary, this study demonstrates how a modelling approach based on national and clinical administrative datasets can be used to estimate and compare the expected impact of different approaches to centralising cancer services on patient travel times, equity in access to services, patient outcomes, and hospital workload. Rectal cancer surgery in the NHS in England was used as an example but this approach can be applied to other cancers and treatment modalities, as well as to patients with complex non-malignant conditions and in different health-care systems. The health service planning tool provides explicit estimates of the expected consequences of different centralisation scenarios outlining relevant trade-offs that can guide often controversial and sensitive decisions about closure of centres providing specialist services.

Contributors

AA and JvdM were involved in conceptualisation of this study. AA, LH, SvdG, and DL were involved in the formal data analysis. AA, LH, JvdM, MV, and SvdG were involved in the methods development. AA, RS, MV, and JvdM were involved in data interpretation. AA and LH wrote the original draft of the paper. LH and DL produced the manuscript figures and tables. AA, LH, SvdG, DL, JB, YL, DJ, RS, MV, and JvdM were involved in reviewing and editing drafts of the paper. LH and AA accessed and verified the raw data used in this study. All authors had full access to data in the study and had final responsibility for the decision to submit for publication.

Declaration of interests

JB reports grants from the Spanish Research Institute Carlos III and AGAUR. YL reports consulting fees from AstraZeneca paid to Ghent University Hospital, and current grants for the ImmunoSABR study and HERO-VBHC chair paid to the Ghent University Hospital. All other authors declare no competing interests.

Data sharing

This study was based on data from the National Cancer Registration and Analysis Service (NCRAS). We do not own these data and hence are not permitted to share them in the original form. The data are available from NHS Digital through the Data Access Request Services (DARS). The model specification Stata do-files are available on request via email to the corresponding author.

For the **data** see https://digital.nhs.uk/services/data-access-request-service-dars

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