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Quantifying the cost savings and health impacts of improving colonoscopy quality: an economic evaluation

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ABSTRACT

Objective To estimate and quantify the cost implications and health impacts of improving the performance of English endoscopy services to the optimum quality as defined by postcolonoscopy colorectal cancer (PCCRC) rates.

Design A semi-Markov state-transition model was constructed, following the logical treatment pathway of individuals who could potentially undergo a diagnostic colonoscopy. The model consisted of three identical arms, each representing a high, middle or low-performing trust's endoscopy service, defined by PCCRC rates. A cohort of 40-year-old individuals was simulated in each arm of the model. The model's time horizon was when the cohort reached 90 years of age and the total costs and quality-adjusted life-years (QALYs) were calculated for all trusts. Scenario and sensitivity analyses were also conducted.

Results A 40-year-old individual gains 0.0006 QALYs and savings of £6.75 over the model lifetime by attending a high-performing trust compared with attending a middle-performing trust and gains 0.0012 QALYs and savings of £14.64 compared with attending a low-performing trust. For the population of England aged between 40 and 86, if all low and middle-performing trusts were improved to the level of a high-performing trust, QALY gains of 14 044 and cost savings of £249 311 295 are possible. Higher quality trusts dominated lower quality trusts; any improvement in the PCCRC rate was cost-effective.

Conclusion Improving the quality of endoscopy services would lead to QALY gains among the population, in addition to cost savings to the healthcare provider. If all middle and low-performing trusts were improved to the level of a high-performing trust, our results estimate that the English National Health Service would save approximately £5 million per year.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Despite colonoscopies being the gold standard diagnostic test for colorectal cancer, there exists significant variation in the quality of colonoscopies performed at endoscopy services. Previous research has shown endoscopy services with higher adenoma detection rates are associated with lower lifetime risks of colorectal cancer and colorectal cancer mortality without being associated with higher costs.

WHAT THIS STUDY ADDS

⇒ This is the first study internationally to quantify the total costs and quality-adjusted life-years for simulated individuals attending endoscopy services with different postcolonoscopy colorectal cancer rates; a measure which provides a more complete picture of the quality of an endoscopy service. This allowed cost-effectiveness analyses to be performed comparing high, middle and low-performing trusts and provides the potential cost savings and quality-adjusted life-year gains that could be realised by quality improvement or by eliminating unwarranted variation in quality.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our study demonstrates the importance of considering the quality, and prioritisation of high-quality endoscopy services during commissioning, and supporting lower performing endoscopy services to engage in quality improvement.

INTRODUCTION

Colorectal cancer (CRC) is a major public health problem, with more than 1.9 million new diagnoses worldwide each year.[1] Within the UK there are

>40 000 new diagnoses each year.[2] Colonoscopy is the gold standard diagnostic test for CRC, and it prevents CRC through polyp detection and resection. As such, it is a key intervention to improve patient outcomes (in terms of both life-years and quality-adjusted life-years (QALYs)). However, colonoscopy is not perfect, and cancers are detected within months or years of having a cancer-negative colonoscopy.[3] A CRC diagnosed after a cancer-negative colonoscopy is called postcolonoscopy colorectal cancer (PCCRC).[4] Within many countries, including England, there is variation in the rates of PCCRCs between endoscopy services.[5–8] This variation exists after adjustment for associated risk factors, such as age, sex, Index of Multiple Deprivation income category and comorbidity score, and is therefore unwarranted.[5] Patients of colonoscopists with low adenoma detection rates (ADRs) have higher PCCRC incidence and CRC-related mortality rates.[9] Thus, people die unnecessarily from variation in endoscopy service quality.

PCCRCs incur additional costs treating more advanced cancers resulting from delayed diagnosis, or treating cancers that could have been prevented.[10] Previous economic evaluations have been performed on the cost-effectiveness of bowel cancer screening programmes, of which colonoscopy is an integral part.[11–13] In the USA, the effect of variation in ADR on the outcomes of bowel cancer shows that higher ADRs are associated with lower lifetime risks of CRC and CRC mortality without associated higher costs.[14 15]

This study is the first economic evaluation worldwide to compare the quality of endoscopy services using the PCCRC rate as the quality indicator and the first economic evaluation of the quality of endoscopy services in the English National Health Service (NHS).

The aim of this study was to estimate and quantify the cost and health outcome implications of moving to a service of optimal quality from either a middle or low-performing trust (an organisational unit of one or more hospitals and including an endoscopy service). We conducted a cost-effectiveness analysis from an NHS England (funder) perspective comparing high, middle and low-performing trusts, estimating and quantifying costs and QALYs and presenting differences for an individual simulated patient and the eligible population of England. This study was part of the National Endoscopy Database (NED) Automated Performance Reports to Improve Quality Outcomes Trial study.[16]

METHODS

Study design

The cost-effectiveness of endoscopy services with varying levels of quality (defined by different PCCRC rates) was analysed using a semi-Markov state-transition model. A Markov model is an analytical framework that uses 'health states' to represent all possible outcomes and events that can occur to simulated individuals due to an intervention of interest. These health states are mutually exclusive and exhaustive and so all simulated individuals in the model can and must be in only one of these health states at any given time. At the end of a 'cycle' (a discreet time period, representing 1 year for this model), the simulated individuals can remain in their health state or move between health states. The probability of each movement is known as the 'transitional probability'. True Markov processes are time independent. That is, all transitional probabilities are assumed to be constant over time. To avoid this assumption, and to introduce transitional probabilities which can vary over time into the model, a semi-Markov process (or time-dependant Markov process) was used.[17] Each cycle spent in a particular health state was associated with a particular state-specific utility score (whereby 0='dead' and 1='perfect health') and, where appropriate, transitioning between states incurred costs. The average total cost per individual and the average total utility gained per individual was obtained by summing the costs and utility score of each cycle of the model over its lifetime. PCCRC rates for 107 trusts were obtained from Burr *et al*, based on 126 152 cases of CRC which occurred up to 3 years after colonoscopy performed within the context of the English NHS between 1 January 2005 and 31 December 2013.[5] This included all procedures performed by NHS providers on private patients treated at NHS centres, or by independent providers paid for by the NHS. The trusts were ranked from the highest performing to the lowest performing and, for the purposes of this study, were grouped into high-performing trusts (defined as the average PCCRC rate of the top 25% of trusts), middle-performing trusts (middle 50%) and low-performing trusts (bottom 25%). A cohort of identical individuals was simulated in the model, each of whom attended a high, middle or low-performing trust. It was assumed that each cohort of simulated individuals could only attend one type of endoscopy service in terms of quality over their lifetime and as such the three types of trusts are mutually exclusive healthcare programmes. An incremental cost-effectiveness ratio was calculated to compare the different levels of trust quality in each arm.[18] The costing perspective was that of NHS England with all prices being in pounds sterling (£) using 2020–2021 prices. For the cost-utility analysis, health outcomes were valued in terms of EQ-5D-derived QALYs.[19] Costs and QALYs were discounted at a rate of 3.5% to take account of the impact of time on these outcomes.[20] The results of the model are presented in terms of cost-effectiveness at a simulated individual level which was then aggregated to a national level in terms of the population of England. A transitional probability (estimated from population and cancer incidence statistics) of undergoing a colonoscopy was applied to the cohort each cycle; however, not all individuals would undergo a

colonoscopy over the lifetime of the model. Thus, the model estimates the total cost and QALYs for a simulated individual who *could potentially undergo* a colonoscopy (derived from specific probabilities), not for an individual who does undergo a colonoscopy; similarly, national extrapolations are therefore for the whole population who could potentially undergo a colonoscopy (as opposed to those who do). In these extrapolations, based on expert opinion, it was assumed that, if an individual required a colonoscopy, 25% of the population would attend a low-performing trust, 50% would attend a middle-performing trust and 25% would attend a high-performing trust. The cost-effectiveness analysis was reported in accordance with the Consolidated Health Economic Evaluation Reporting Standards statement (available in the online supplemental material).[21]

Model

The model was constructed in TreeAge (TreeAge Software, Williamstown, Massachusetts, USA; 2021), and followed the International Society for Pharmacoeconomics and Outcomes Research good practice guidelines.[22] The model, starting with a cohort of patients aged 40 years, was run in 1-year cycles over a 50-year time horizon until the cohort reached 90 years of age. It was agreed through expert clinical opinion that the model should start with a cohort aged 40 (due to disease prevalence) and the model should run a maximum of 50 years to capture cost and health impacts that would accrue over the individual's lifetime.

At the start of the model, all individuals began in the 'Alive and Well' health state (figure 1). This health state assumed that individuals did not have a previous diagnosis of CRC and had not undergone a colonoscopy within the previous 3 years. From this state, they could remain in this health state, undergo a colonoscopy or die. If an individual underwent a colonoscopy, they could either be diagnosed with CRC, undergo a polypectomy (and immediately transition to the 'Post Polypectomy Y1' health state) or neither (and immediately transition to the 'Post no Polypectomy Y1' health state).

As the probability of developing a PCCRC differed over the 3 years after colonoscopy, the 'Post Polypectomy' health state and the 'Post no Polypectomy' health state were modelled as three tunnel states. Within each tunnel state, an individual could die and move to the 'death' state; develop a PCCRC and transition into one of the eight CRC health states; or transition to the next tunnel state. If an individual had transitioned through all three 'Post No Polypectomy' tunnel states,

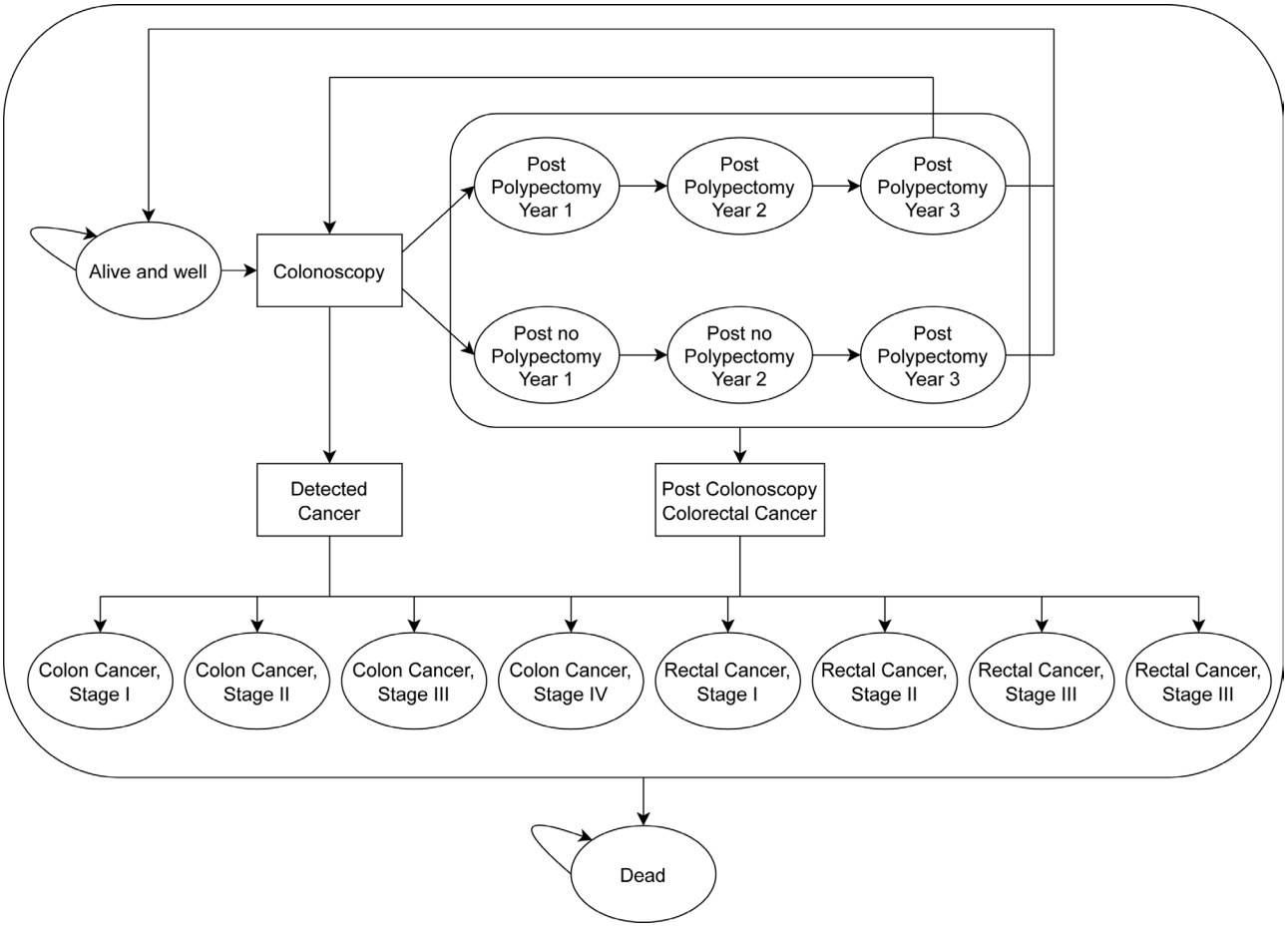

Figure 1 Schematic diagram of model states and possible transitions for one arm of the model.

they return to the 'Alive and Well' health state. Based on expert clinical opinion regarding implementation of published guidance, a proportion of individuals who transitioned through all three 'Post Polypectomy' tunnel states were classified as high risk based on their colonoscopy findings and underwent a (surveillance) colonoscopy.[23] Those who were not high risk transitioned to the 'Alive and Well' health state.

Individuals diagnosed with CRC (at colonoscopy or as a PCCRC) entered one of eight CRC health states, which represented colon and rectal cancer stages I–IV separately. The data used to parameterise the costs of cancer treatments and the mortality rates of individuals with CRC for each stage of CRC included the costs/mortality of the individuals progressing to more severe CRC states and the individuals whose treatment was successful. As such, it was assumed that each CRC health state represented the lifetime outcomes of all individuals who were diagnosed with that cancer stage and therefore, once in these health states, an individual could only remain in their current state or transition to the terminal state 'death'.

The absorbing state in the model was death, once an individual transitioned the 'death' state, they remained there for the remainder of the model's lifetime. Any individual could move into this state from any other state. The model included two elements of mortality: mortality in individuals with CRC and mortality in individuals without CRC. Mortality in individuals with CRC was the probability of the individual with CRC dying, either from CRC or from any other cause. This was dependent on the individual's age, the length of time the individual had been in a CRC state, the stage of the cancer and whether the cancer was colon cancer or rectal cancer. Individuals in all non-CRC health states were assigned a probability of dying based on all-cause mortality, which depended on the individuals' age.

Model parameters

Transitional probabilities were derived from the literature or, where necessary, from expert clinical opinion based on a plausible treatment pathway (online supplemental tables 1–5).[23] The PCCRC rates were obtained from the literature, as were the cancer staging distribution, the distribution of PCCRCs over the 3 years and the proportion of colonoscopies that result in a CRC diagnosis within 6 months (the detected cancer rate).[5] On the basis of expert opinion and the lack of data on the detected cancer rates at trust level, it was assumed that all three groups of trusts had the same detected cancer rate. The polyp detection rates for high, middle and low-performing trusts were obtained from the NED.[24] All mortality rates were obtained from the Office for National Statistics.[25–27] It was assumed (via expert opinion) that 5% of all colonoscopies would be high-risk polypectomies (undergoing a surveillance colonoscopy after 3 years) and this would be the same for all trusts. Using population and cancer incidence statistics for England, an age-stratified rate was estimated to indicate the proportion of individuals that would undergo a colonoscopy at each age.[26 28 29] No assumptions were made on which individuals were eligible for a colonoscopy or on which individuals take up the offer; the transitional probability of undergoing a colonoscopy was applied to all individuals equally. For this study, a PCCRC is defined to occur up to 3 years after colonoscopy.[28] Therefore, it was assumed that no colonoscopies were performed in the last three cycles, allowing the full effects of a colonoscopy to be captured. A half-cycle correction was adopted for the model.[30]

Costs

The model included two cost elements: those associated with a colonoscopy and those associated with the subsequent diagnosis, treatment and follow-up of CRCs. The cost of a colonoscopy was obtained and valued using the appropriate NHS tariff cost and included the colonoscopy itself and the additional cost of any polypectomies required.[31] The model does not include the costs of identifying those eligible for colonoscopy as it was assumed these would not differ between trusts of differing quality. The costs of the diagnosis, treatment and follow-up of CRCs were derived from Tilson *et al* and were converted from euros to pound sterling and inflated to reflect 2020–2021 period.[10 32 33]

Health outcome valuation

The utility scores for all non-CRC states were derived from the age-adjusted EQ-5D index population norms using a UK-specific value set.[34] Any decrement in utility due to a colonoscopy was not included as it was assumed that such a short-term disutility over an individual's lifetime would be negligible. For the CRC health states, a utility decrement to the age-adjusted EQ-5D index population norms was derived from Ness *et al*.[35 36] Individuals who died were assigned a utility value of zero.

Additional assumptions

It was assumed that the cancer stage distribution was the same for colon and rectal cancers due to lack of data in the literature. It was also assumed, again due to the lack of data, that the PCCRC rate did not change as the cohort ages. The mortality rate for individuals with CRC after 5 years was assumed to be equal to the mortality rate for years 4 and 5 due to the paucity of data on long-term mortality rates by age and cancer stage. Additionally, it was assumed that individuals would only undergo a colonoscopy within 3 years of a previous one as part of a PCCRC diagnosis. Finally, an assumption was made that non-CRC mortality follows the UK national life tables and that

colonoscopy patients are no more or less likely to die than on average.

Scenario and sensitivity analyses

Differences in endoscopy service quality would affect more individuals than the cohort of 40 year-olds included in the base case analysis; improvements in quality would also affect cohorts with starting ages above 40 years old. To explore this, scenario analysis was undertaken whereby the analysis was repeated but the starting age of the cohort was varied from 40 to 86 (inclusive). While the starting age of the cohort varied, the time horizon remained 90 years of age. From this, a weighted average of the total costs and QALYs for an individual was calculated, weighted according to the age distribution of England.[26]

Probabilistic sensitivity analysis was undertaken to explore the impact of alternative parameter values on the cost-effectiveness of high-performing trusts compared with lower performing trusts and to examine uncertainty in the model. Parameters used within the model were sampled from their distributions (online supplemental table 1). The model was run 100 000 times to generate a distribution of expected costs and health outcomes; the results are presented as cost-effectiveness acceptability curves.[37]

RESULTS

Under our assumptions, the base case cost-effectiveness analysis showed that, over the model lifetime, an individual who attended a high-performing trust would have an additional 0.0006 QALYs and would save £6.75 in costs compared with the same individual attending a middle-performing trust (table 1). An individual attending a high-performing trust instead of a low-performing trust would gain 0.0012 QALYs and save £14.64. The high-performing trusts dominated both middle and low-performing trusts, with the high-performing trusts having both lower costs and higher QALYs. In the base case analysis, the high-performing trusts undertook more colonoscopies in total than the lower quality trusts but experienced fewer total cases of CRC over the model lifetime, due to lower numbers of PCCRCs (online supplemental table 6). As the difference in total cases of CRC is small between high, middle and low-performing trusts on an individual level, the cost savings and QALY gains per individual are also relatively small. However, the potential benefit of improvement at population level in the lower performing trusts is large. The population aged 40 in England was 661 552 in 2017.[26] Improving all trusts to the level of a high-performing trust leads to total QALY gains of 397 and total cost savings of £4 654 018 over 50 years.

In the scenario analysis, where the cohort's starting age was varied, the high-performing trusts still dominated the lower performing trusts, with the lower performing trusts having lower QALYs and greater costs. Assuming the age distribution of England, 0.0005 additional QALYs and cost savings of £8.94 per individual could be achieved by attending a high-performing trust compared with a middle-performing trust, and 0.0011 additional QALYs and cost savings of £19.40 could be achieved by attending a high-performing trust compared with a low-performing trust. Using the same assumptions as the base case analysis, the population that could benefit from these improvements is large. The population aged 40–86 in England was 26 750 139 in 2017.[26] Over the following 50 years, improving the middle and low-performing trusts to the quality of the high-performing trusts results in QALY gains of 14 044 and cost savings of £249 311 295. These findings approximate to a crude estimate of cost savings to the NHS of £5 000 000/year over the next 50 years.

For the probabilistic sensitivity analysis, the results showed that, for the majority of runs of the model, the high-performing trusts dominated the lower performing trusts, with a greater number of QALYs and lower total costs for individuals who attended

Table 1 Results of the base case and scenario analyses (per individual)

Scenario	Trust	Costs (£)	QALYs	ICER (£)
Base case analysis (results for a cohort aged 40)	High (top 25%)	£657.72	18.0976	
	Middle (middle 50%)	£664.47	18.0970	Dominated
	Difference*	−£6.75	0.0006	
	Low (bottom 25%)	£672.36	18.0964	Dominated
	Difference†	−£14.64	0.0012	
Scenario analysis (weighted average results for a cohort aged between 40 and 86)	High (top 25%)	£869.06	12.0817	
	Middle (middle 50%)	£878.00	12.0812	Dominated
	Difference*	−£8.94	0.0005	
	Low (bottom 25%)	£888.46	12.0806	Dominated
	Difference†	−£19.40	0.0011	

Costs and ICERs are to two decimal places while QALYs are to four decimal places.
*This is the difference between a high-performing trust and a middle-performing trust.
†This is the difference between a high-performing trust and a low-performing trust.
ICER, incremental cost-effectiveness ratio; QALYs, quality-adjusted life-years.

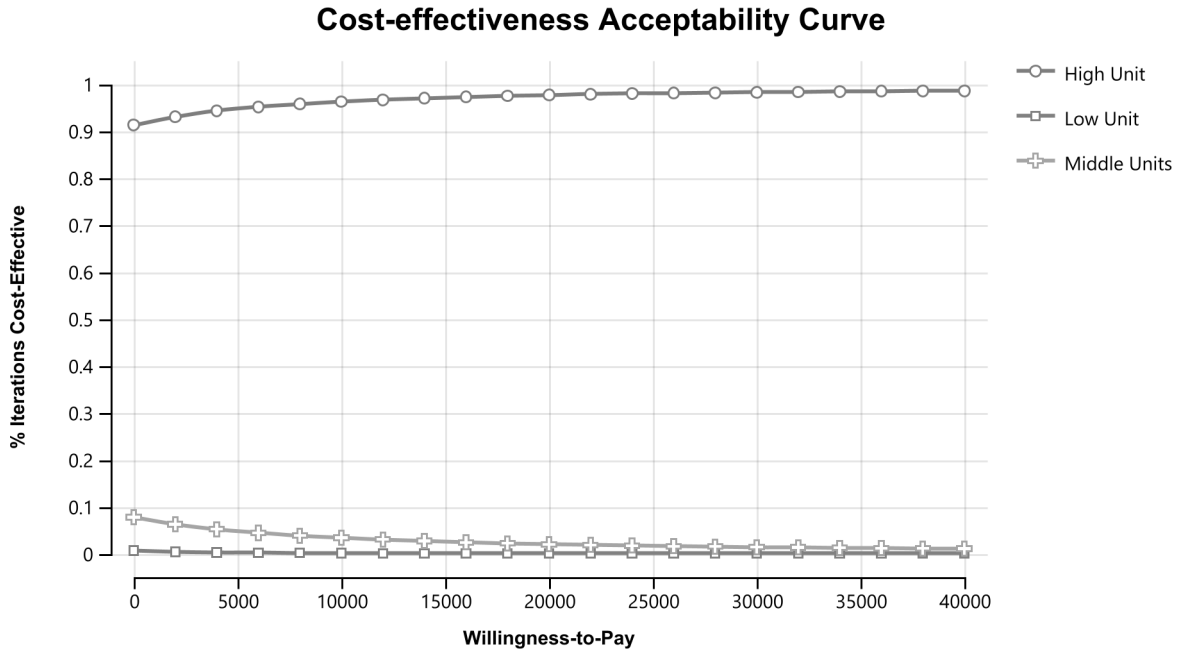

Figure 2 Cost-effectiveness acceptability curve for the probabilistic sensitivity analysis.

the high-performing trusts compared with individuals who attended the lower performing trusts. For all willingness-to-pay thresholds, the high-performing trusts had >90% probability of being cost-effective (as shown in figures 2–4).

DISCUSSION

This is the first paper to estimate the cost implications and cost-effectiveness of endoscopy services of varying quality (measured in terms of PCCRC rates) globally and in England. Our model found, perhaps unsurprisingly, that there are cost savings and health benefits (in QALYs) for individuals attending better quality trust endoscopy services. In all analyses, the higher quality endoscopy services dominated lower quality services (ie, they had lower costs and higher QALYs). Improving the quality of all services to high would provide estimated total QALY gains of 14 044 and total cost savings of £249 311 295 over 50 years. The probabilistic sensitivity analysis, in the vast majority of runs, suggests that the high-performing trusts are cost-effective compared with middle and low-performing trusts. At a willingness-to-pay threshold of £20 000 per QALY, the high-performing trusts were 97.7% cost-effective.[38]

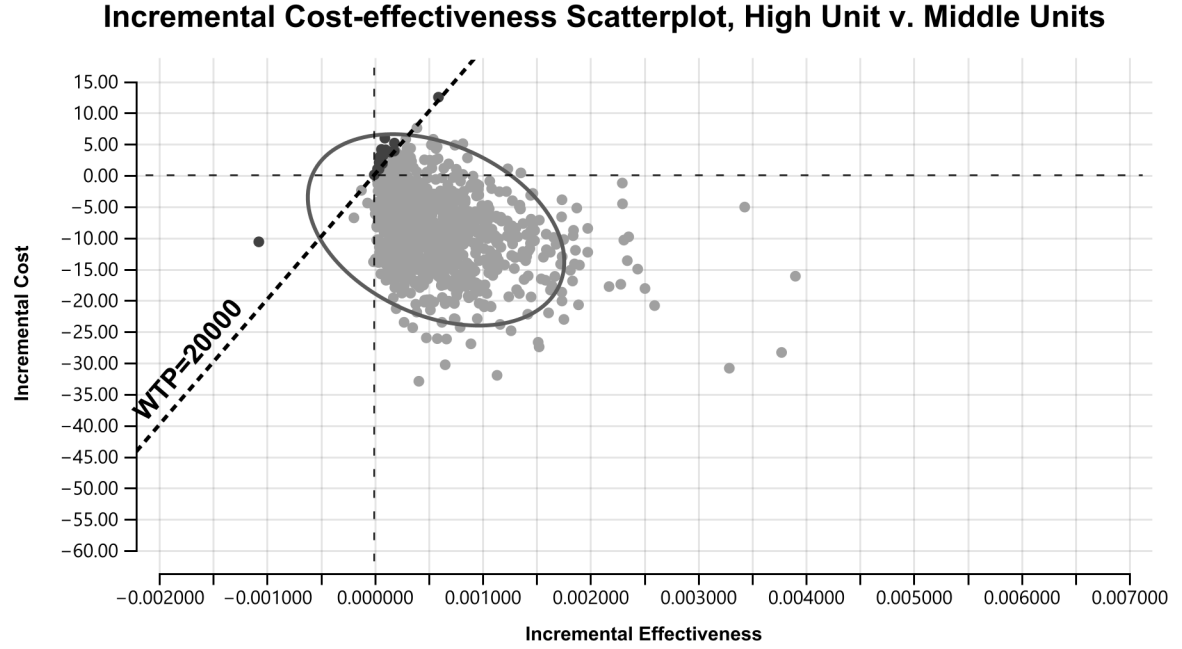

Figure 3 Incremental cost-effectiveness ratio scatterplot for high-performing trusts compared with middle-performing trusts. WTP, willingness to pay.

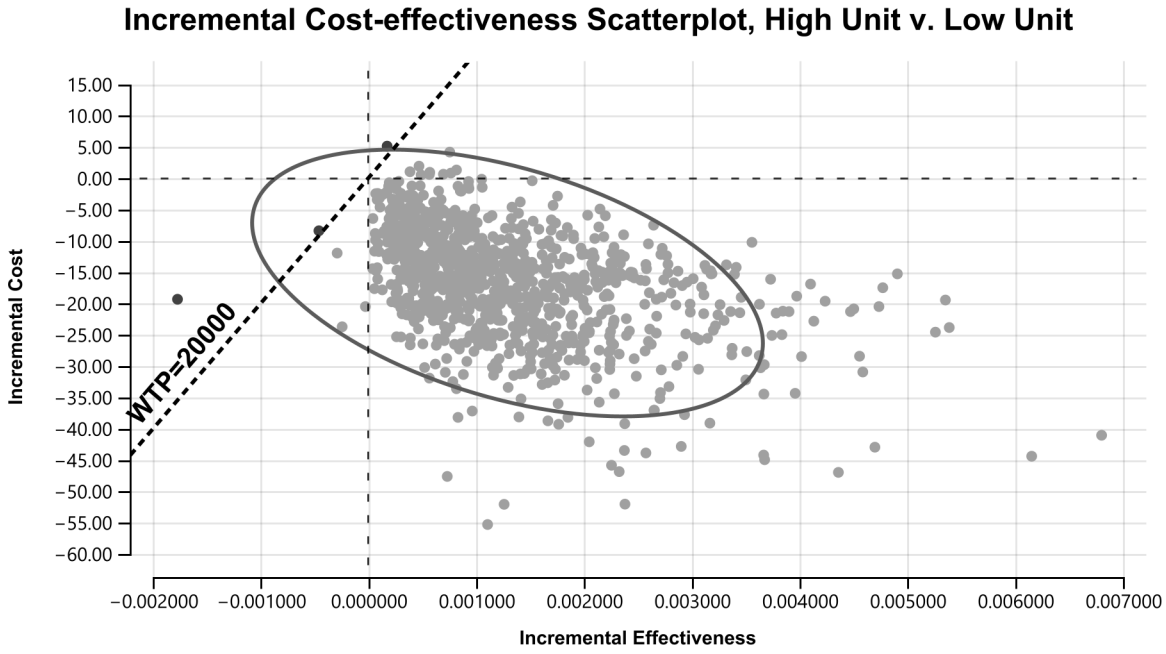

Figure 4 Incremental cost-effectiveness ratio scatterplot for high-performing trusts compared with low-performing trusts. WTP, willingness to pay.

Anderson *et al* found that >80% of PCCRCs are likely preventable and proposed a target PCCRC rate of <2%.[39] Assuming <3% is achievable, the potential QALY gains and cost savings of improving all trusts to this target rate are significant. On average, individuals aged 40–86 who would attend a trust with a PCCRC rate of 3% would have a total of 12.0823 QALYs over the model lifetime and cost £859.72. Improving all trusts to a 3% PCCRC rate leads to QALY gains of 30 094 and cost savings of £499 147 594 over 50 years.

Previous studies have shown that services with higher quality performance metrics result in fewer CRCs, lower costs and increased QALYs among the population.[13 14] However, these studies defined the quality of a service by the ADR and were conducted in the USA. While there is evidence of a relationship between the ADR and PCCRC rate, using the PCCRC rate as the indicator takes account of the total effects of an endoscopy service, not just the quality of the procedure. It therefore provides a more complete picture.[4] This approach has allowed direct capture of the costs and QALY losses to individuals and the NHS of attending a middle or low-performing trust.[6]

In 2019, the NHS released their Long-Term Cancer Plan.[40] This plan aimed to improve patient experiences of care and quality of life and reduce variation and inequalities across the NHS. Our model has shown that improving the quality of trust endoscopy services achieves these aims at lower NHS costs. Cancer prevention, another key goal of the Plan, is achieved with higher quality colonoscopy services. Reducing health inequalities is exemplified in Core20PLUS5 in which one of the five clinical areas of focus is early cancer diagnosis.[41] The variation in PCCRC rates across NHS England is a structural inequality, with individuals experiencing unfair, avoidable differences in health, depending on the quality of the trust endoscopy service they attend. The model shows that improving the quality of the index colonoscopy at all trusts to the same, high standard reduces health inequalities.

The definition of PCCRCs used within the model limited the differences between the trusts to 3 years after colonoscopy. However, the benefits of high-quality lower gastrointestinal endoscopy (in terms of QALYs gain, cost savings and cancers potentially avoided) last beyond this period, in some circumstances up to 17 years.[6 8 42] Cancers appearing over long timelines are likely to be cancers that could have been prevented. Such benefits of high-quality colonoscopy beyond 3 years are not captured within the analysis, thus the estimated benefits are an underestimate of the true benefits.

Several assumptions regarding the economic model were made due to a paucity of relevant data. There was a lack of colonoscopy rates available in the literature. Although an estimate of the colonoscopy rate was calculated, without the true rate, there is uncertainty about the true total costs and QALYs of each trust. In addition, the cost of a colonoscopy (with and without a polypectomy) was assumed to be same for all trusts. Any difference in the cost of a colonoscopy would have an impact on the total costs. The detected cancer rates were not available, and it was assumed this rate was equal for all trusts. Although a difference in the detected cancer rates between trusts of differing quality is likely, lack of available data covering the same time period as the PCCRC rate data has prevented inclusion of this in the model. As such, the cost and QALY differences between the trusts are driven by differences in PCCRCs arising from missed polyps.

Another limitation is that the calculation of benchmark PCCRC-3yr rates is dependent on the accuracy of national datasets.[43] Cancer registries have rigorous validation processes, so cancer diagnosis is generally reliable. The exact timing of the diagnosis and the timing and occurrence of colonoscopy are less reliable, and such errors can affect the calculation of benchmark PCCRC-3yr rates. In a national audit of PCCRCs only 5% were correctly rejected for these reasons so the potential impact on rates is small.[5] Moreover, we think it improbable that systematic coding errors account for the large variation in PCCRC rates across the country. Finally, the PCCRC rates used to define the quality of the trusts were from 2011 to 2013. Although the nature of PCCRCs means that all PCCRC data will be at least several years old, it is possible that the quality of English endoscopy services has improved since the PCCRC rates were collected and benefits of improvements may be overstated.

The limitations and uncertainty within the model largely correspond to data requirements. Collecting and reporting complete and comprehensive data from endoscopy services should be a priority in the future. Accurate information on colonoscopy rates would allow a more precise estimate of the cost-effectiveness of high-performing trusts compared with lower performing trusts. In addition, our model does not incorporate or examine the costs and effects of an intervention to improve the quality of a trust endoscopy service. Future research will need to focus on this aspect. However, the likely costs of interventions to reduce PCCRC rates are likely to be a small fraction of the savings.[44]

Colonoscopy is an essential and commonly used diagnostic test for lower gastrointestinal symptoms and as part of CRC screening. However, significant variation in the quality of endoscopy services exists.[5] Our analysis indicates this variation leads to increased costs and lower quality of life among the population. Increasing the quality of lower performing endoscopy services is likely to be a very cost-effective strategy, although further research is required to identify how to achieve this. Interventions to improve quality have the potential to lead to significant cost savings to the NHS and improved health-related quality of life among the population.[16 44] If all middle and low-performing trusts were improved to the level of a high-performing trust overnight, our results estimate a saving of approximately £5 million/year in England.

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Contributors SM designed the model and drafted the manuscript. MDR was the chief investigator for the NED-APRIQOT project. MDR and RV provided clinical advice. All authors assisted on the design and construction of the model, critically reviewed the manuscript, contributed to its revisions and approved the final version submitted. JG is the guarantor.

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