Original Study

Minimally Invasive Surgery for Colorectal Cancer: Benchmarking Uptake for a Regional Improvement Programme

John C. Taylor,[1,3] Dermot Burke,[1] Lene H. Iversen,[2] Rebecca J. Birch,[1,3] Paul J. Finan,[1,3] Mark M. Iles,[3,4] Philip Quirke,[1] Eva J.A. Morris[5], on behalf of the YCR BCIP Study Group

Abstract

Use of minimally invasive surgery can benefit recovery in patients treated for colorectal cancer. We investigated its uptake in England between 2007 and 2021. As expected, use of laparoscopic and robotic surgery increased but we observed wide variation at the hospital level. Our data-driven approach identified potential outlying hospitals for further investigation through a regional cancer improvement programme.

Background: The uptake of minimally invasive surgery (MIS) for patients with colorectal cancer has progressed at differing rates, both across countries, and within countries. This study aimed to investigate uptake for a regional colorectal cancer improvement programme in England.**Method:** We calculated the proportion of patients receiving elective laparoscopic and robot-assisted surgery amongst those diagnosed with colorectal cancer over 3 time periods (2007-2011, 2012-2016 and 2017-2021) in hospitals participating in the Yorkshire Cancer Research Bowel Cancer Improvement Programme (YCR BCIP). These were benchmarked against national rates. Regression analysis and funnel plots were used to develop a data driven approach for analysing trends in the use of MIS at hospitals in the programme.**Results:** In England, resections performed by MIS increased from 34.9% to 72.9% for colon cancer and from 28.8% to 72.5% for rectal cancer. Robot-assisted surgery increased from 0.1% to 2.7% for colon cancer and from 0.2% to 7.9% for rectal cancer. Wide variation in the uptake of MIS was observed at a hospital level. Detailed analysis of the YCR BCIP region identified a decreasing number of surgical departments, since the start of the programme, as potential outliers for MIS when compared to the English national average.**Conclusion:** Wide variation in use of MIS for colorectal cancer exists within the English National Health Service and a data-driven approach can help identify outlying hospitals. Addressing some of the challenges behind the uptake of MIS, such as ensuring adequate provision of surgical training and equipment, could help increase its use.

Clinical Colorectal Cancer, Vol. 23, No. 4, 382–391 © 2024 The Author(s). Published by Elsevier Inc.

Keywords: Laparoscopic surgery, Robotic surgery, Population-based, Denmark, England

Introduction

In the 1990s, minimally invasive surgery (MIS), such as laparoscopic surgery, emerged as an alternative to traditional open surgery for the treatment of colorectal cancer.[1] Subsequently, a number of randomised controlled trials demonstrated laparoscopic surgery was as effective as open surgery in terms of recurrence and survival rates, but with a potential to reduce hospital stay and improve recovery.[2-4] Following these studies, English guidance issued by The National Institute for Health and Care Excellence (NICE) was updated in 2006 to recommend laparoscopic surgery as an alternative to open resection for some patients, by suitably trained surgeons and after informed discussion between surgeon and patient.[5] Subsequent retrospective studies have demonstrated the safety of laparoscopic

Abbreviations: MDT, multidisciplinary team; MIS, minimally invasive surgery.

[1]Leeds Institute of Medical Research at St James's, University of Leeds, Leeds, United Kingdom
[2]Department of Surgery, Aarhus University Hospital, and Danish Colorectal Cancer Group, Aarhus, Denmark
[3]Leeds Institute for Data Analytics, University of Leeds, Leeds, United Kingdom
[4]NIHR Leeds Biomedical Research Centre, Leeds Teaching Hospitals NHS Trust, Leeds, United Kingdom
[5]Nuffield Department of Population Health, Big Data Institute, University of Oxford, Oxford, United Kingdom

Submitted: Jul 7, 2023; Revised: May 15, 2024; Accepted: May 28, 2024; Epub: 18 June 2024

Address for correspondence: J. C. Taylor, MSc, Leeds Institute for Data Analytics, University of Leeds, Worsley Building, LS2 9NL, Leeds, United Kingdom.
E-mail contact: j.c.taylor@leeds.ac.uk

https://doi.org/10.1016/j.clcc.2024.05.013

techniques in colorectal cancer with outcomes at least equivalent to open surgery.[6-10]

It has previously been shown that the uptake of MIS varies widely both between and within European countries[7,11] with some adopting the techniques much more readily than others. For example, the percentage of patients undergoing MIS in Denmark increased from < 10% in 2004 to 80% in 2016.[12] The Yorkshire Cancer Research Bowel Cancer Improvement Programme (YCR BCIP) which commenced in 2016, benchmarks surgical metrics (including MIS) of multidisciplinary teams (MDTs) or Hospital Trusts responsible for patient care in Yorkshire, against other regions and English national figures.[13] The results of these are fed back to the regional MDTs, with the aim of reducing the variation in treatment experienced by patients in the region.

The purpose of this population-based study was to compare MIS uptake for patients with colorectal cancer in England, and to develop data driven methodology for identifying trends in MIS for a regional improvement programme.

Patients and Methods

The study population consisted of all patients who had undergone an elective major surgical resection for colorectal cancer (ICD C18-C20) in an English National Health Service (NHS) hospital between 1 January 2007 and 30 June 2021, obtained from the UK Colorectal Cancer Intelligence Hub's colorectal cancer data repository (CORECT-R).[14] This included patients diagnosed between 1 January 2007 and 31 December 2019 provided by the National Cancer Registry and Analysis Service (NCRAS), and those diagnosed between 1 January 2020 and 30 June 2021 extracted from the Rapid Cancer Registrations Dataset (RCRD). The RCRD enables a near-real time analysis of cancer data but less quality assurance is feasible than is adhered to in the gold-standard NCRAS dataset due to the rapidity of the reporting resulting in lower case ascertainment and should therefore be used with caution.

Those treated at 1 of 14 YCR BCIP Hospital Trusts were identified as described previously.[15] In the English NHS, MDTs consist of a team of specialists who are responsible for the treatment plan of patients and include surgeons, oncologists, pathologists, radiologists and nurse specialist, amongst others. Within the YCR BCIP region, 1 MDT covers the care at each hospital Trust, so for the purpose of this paper we have used the term "hospital" in place of MDT or Hospital Trust.

Benchmarking Uptake of Minimally Invasive Surgery

Firstly, we compared the uptake of MIS across all hospitals in the YCR BCIP region. Linked cancer registry and inpatient hospital records (Hospital Episode Statistics) were used to classify major resections for colorectal cancer as laparoscopic (OPCS procedure codes Y751, Y752, Y754, Y755, Y758, and Y759 on the same day of the major resection), robotic (OPCS code Y753 on the same day of major resection) or open (absence of laparoscopic or robotic OPCS codes).[14] The proportion of attempted elective MIS resections were compared in the YCR BCIP region to National figures for colon and rectal cancer over 3 time periods (2007-2011, 2012-2016 and 2017-2021). Similarly, the proportion of MIS resections that were performed as robotic (or robot-assisted) surgery were compared.

A key strategy of YCR BCIP is to benchmark regional care and outcomes in colorectal cancer with that of Denmark, which is of a similar size to the Yorkshire region, has previously implemented a MIS training strategy and also has healthcare provision mainly financed through taxation. Therefore, we obtained the number of elective major resections that were classified as open, laparoscopic, and robotic in patients with colorectal cancer that were reported by the Danish Colorectal Cancer Group (DCCG) for patients diagnosed between 2008 and 2021[16] and used these a benchmark rates in comparison with YCR BCIP figures.

Identifying Regional Outliers and Trends

We investigated the presence of potential outlying hospitals in their use of MIS within the YCR BCIP region. To do this, a multilevel mixed effects logistic regression for MIS use was constructed for 3 time periods (2007-2011, 2012-2016 and 2017-2021) and funnel plots[17] were created from the hospital-specific treatment rates. The 3 periods of time were chosen to cover a time before and after the start of the programme in 2016. Hospital was fitted as a random effect and the model was adjusted for age at diagnosis, sex, deprivation (categorized using quintiles of the income domain of the Index of Multiple Deprivation, IMD), Charlson Comorbidity Index (CCI, categorized as a score of 0, 1, 2, and ≥ 3), stage of disease and tumour site.

In addition, we developed a new approach (described as "tunnel plots") to display the information from several funnel plots over an extended time period, which enabled identification of outliers while taking into account trends over time. Tunnel plots were constructed by splitting the study period into 10 equal time frames and constructing a funnel plot for each of these. The MIS rate, national rate and control limits (at $P = .05$ and $P = .002$) were then taken for each of the 14-regional hospitals at each of the 10 time points and plotted over time (Figure 1). The results were fed back via face-to-face and online meetings between representatives from the YCR BCIP team and the regional surgical teams.

Since the majority of hospitals were found to be not performing any robotic surgery, the use of funnel and tunnel plots would not be suitable. Therefore, to assess regional variation in use of robotic surgery, we reported the observed percentage of MIS performed using robotic surgery by hospital. We classified hospitals as performing robotic surgery if the hospital had at least 2 instances of robotic surgery recorded, and the percentage of robotic surgery accounted for at least 1% of all MIS in the period 2017-2021.

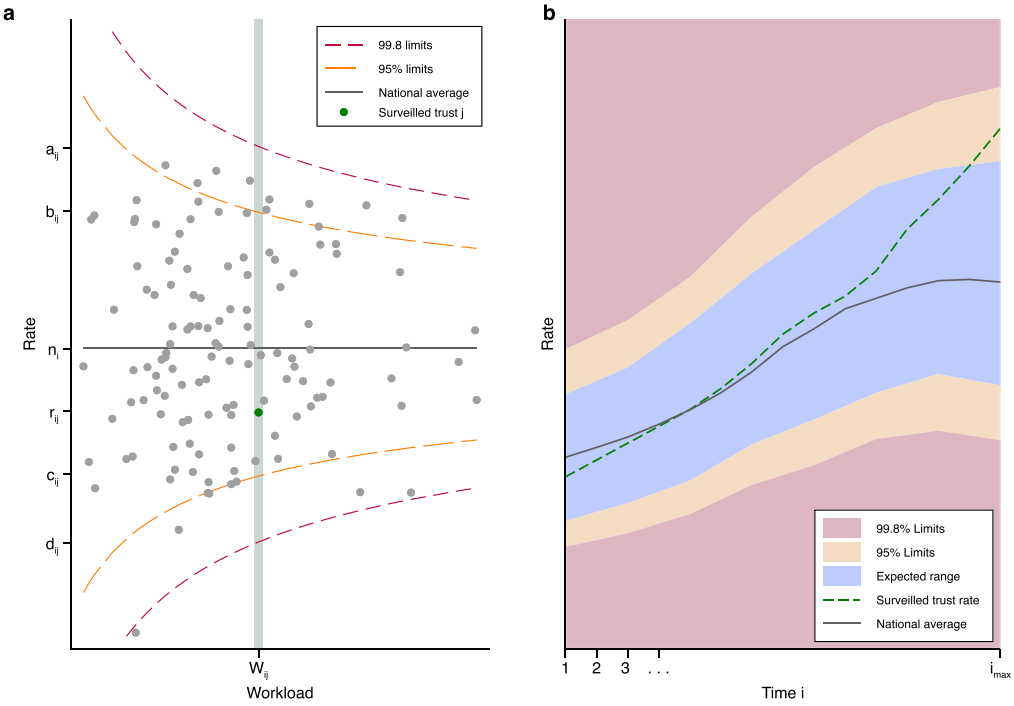
Results

Benchmarking Uptake

A total 185,017 elective resections for colon cancer and 68,890 elective resections for rectal cancer were included in the analysis. The YCR BCIP region accounted for 27,834 (11%) of these. In England, 100,348 (54.2%) colon cancer resection and 34,330 (49.8%) for rectal cancer resection were performed using MIS. Patients characteristics are given in Table 1 (colon cancer) and Table 2 (rectal cancer).

The annual proportion of resections performed using MIS for England, YCR BCIP and Denmark are shown in Figure 2. Slower uptake in MIS was observed for YCR BCIP when compared to

Figure 1 Funnel plots are constructed for each time period *i* and the surveilled trust *j* is identified (A). The corresponding trust rate r_{ij}, 99.8% limits a_{ij} and d_{ij}, 95% limits b_{ij} and c_{ij} at the given trust workload W_{ij} are then plotted with the national rate n_i at each time period to form the tunnel plot (B).



overall English rates in both colon and rectal cancer, but this difference reduced by the latest study period (Supplemental Table S1). In 2017-2021, the percentage of MIS for colon cancer was 69.1% for YCR BCIP compared with the overall English percentage of 72.9%. In rectal cancer the corresponding figures were 67.3% for YCR BCIP and 72.5% for England.

When benchmarking MIS against Danish national figures, uptake in England and YCR BCIP was slower than in Denmark. In 2017-2021 the Danish MIS percentage had reached 87.6% in colon cancer and 92.3% in rectal cancer.

In 2017-2021, the percentage of all resections done by robotic surgery in colon cancer was 2.1% for YCR BCIP compared with the overall English percentage of 2.7% (Supplemental Table S1). In rectal cancer the corresponding figures were 4.7% for YCR BCIP and 7.9% for England. Over the same time period, in Denmark, the percentage of all resections performed using robotic surgery was 13.1% in colon cancer and 47.4% in rectal cancer.

The annual proportion of MIS resections that were performed using robotic surgery for England, YCR BCIP and Denmark are shown in Figure 3. Uptake of robotic surgery in YCR BCIP was slower than in England for rectal cancer, while Denmark had a much quicker uptake than England. Figure 3 shows that by 2021, robotic surgery accounted for over 60% of all Danish rectal cancer resections performed using a MIS technique, compared to < 20% in England.

Identifying Regional Outliers and Trends

The multilevel logistic regression models revealed higher use of MIS within England across all study periods was associated in those aged 60-69 years, residing in the least deprived areas, a CCI score of zero, an early stage tumour and a tumour located in the colon.

YCR BCIP hospitals were identified upon construction of the Funnel plots (Figure 4). In the period before the start of the programme (2012-2016), 7 regional hospitals were found to be potential outlying units for low use of MIS at the 95% confidence limit. In the period after the start of the programme (2017-2021) the number of potential outliers for low use of MIS had reduced to 2 hospitals.

Splitting of the study period into 10 equal time-frames, approximately 18 months (530 days) apart was performed for construction of the tunnel plot. This enabled identification of trends in MIS use for each hospital while maintaining the use of control limits (Figure 5). The following observations were noted for feedback to the regional hospitals: A number of hospital showed a decrease in use of MIS to become low outliers (A and E); the majority of hospitals observed an increase in use or maintained use above the national average; 1 longstanding low outlier experienced a sharp increase to no longer being an outlier (B).

Out of the 122 hospitals in England, 41 were observed to be performing robotic surgery in patients with colon cancer, and 46 were observed to performing robotic surgery in patients with rectal

Figure 2 Percentage of major resections performed using minimally invasive surgery (MIS) for patients with colon and rectal cancer in YCR BCIP hospitals compared to the Danish benchmark.

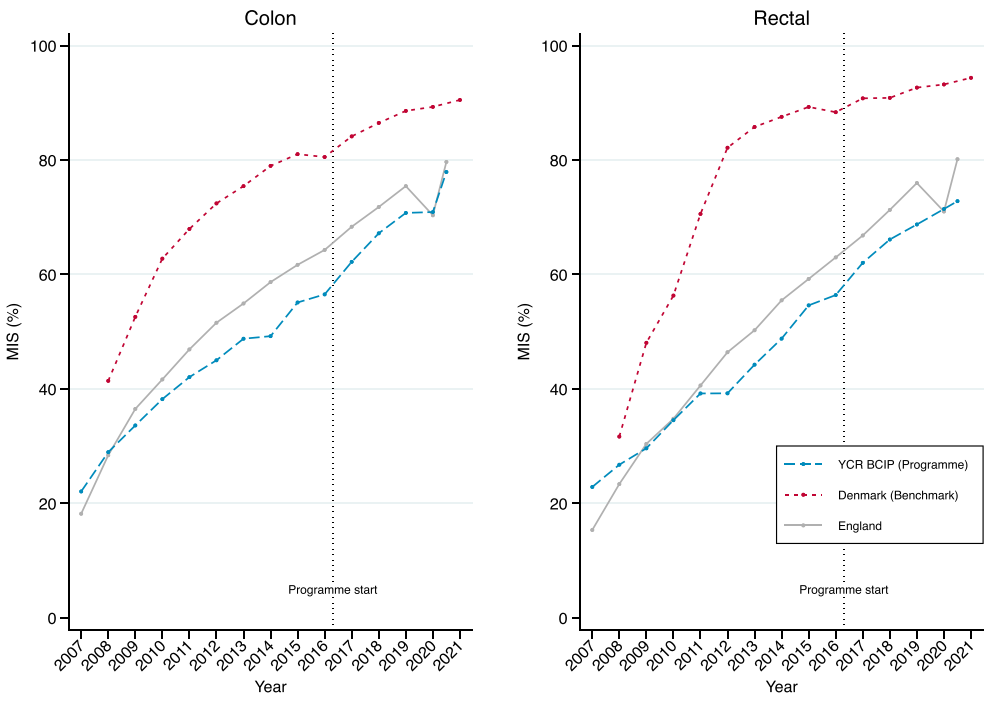


Figure 3 Percentage of minimally invasive surgery (MIS) performed using robotic surgery for patients with colon and rectal cancer in YCR BCIP hospitals compared to the Danish benchmark.

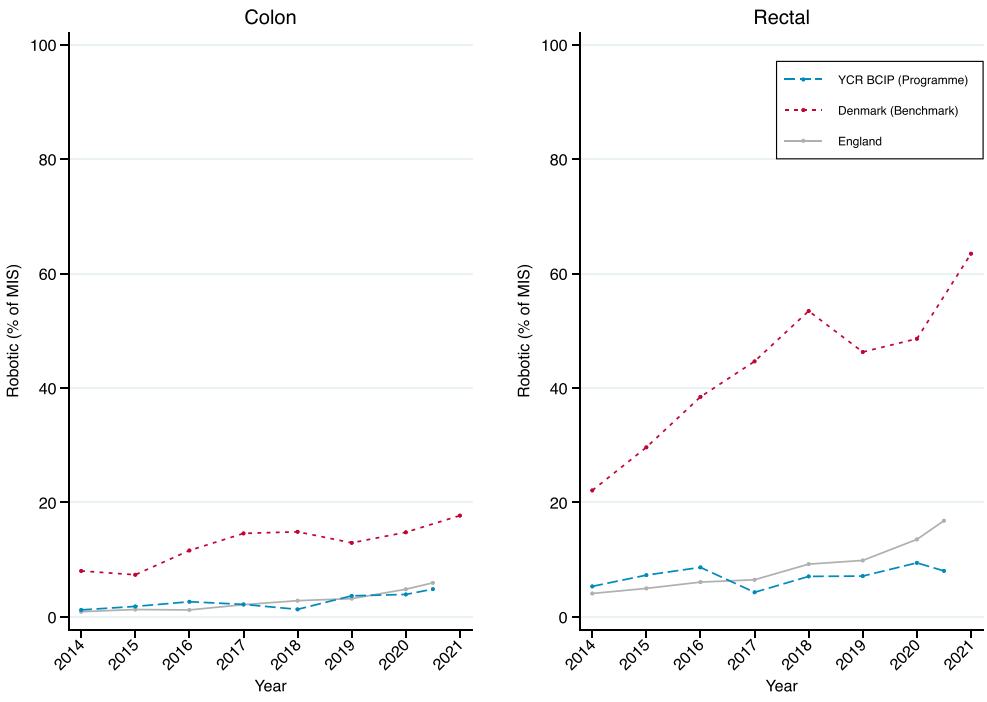


Table 1 Characteristics for Patients With Colon Cancer Undergoing Open, Laparoscopic and Robotic Surgery in England Diagnosed Between 2007 and 2021

		Open		Laparoscopic		Robotic		Total
		N	%	N	%	N	%	
Total		84,669		98,513		1835		185,017
Age	18-59	13,935	*16.5*	15,625	*15.9*	402	*21.9*	29,962
	60-69	21,864	*25.8*	28,338	*28.8*	576	*31.4*	50,778
	70-79	28,957	*34.2*	34,640	*35.2*	619	*33.7*	64,216
	≥ 80	19,913	*23.5*	19,910	*20.2*	238	*13.0*	40,061
Sex	Male	44,395	*52.4*	53,171	*54.0*	1044	*56.9*	98,610
	Female	40,274	*47.6*	45,342	*46.0*	791	*43.1*	86,407
IMD	1—least deprived	17,636	*20.8*	22,093	*20.8*	372	*20.3*	40,101
	2	19,043	*22.5*	22,808	*22.5*	381	*20.8*	42,232
	3	17,566	*20.8*	20,569	*20.9*	379	*20.7*	38,514
	4	15,939	*18.8*	18,101	*18.4*	372	*20.3*	34,412
	5—most deprived	14,485	*17.1*	14,942	*15.2*	331	*18.0*	29,758
CCI score	0	61,605	*72.8*	76,814	*78.0*	1526	*83.2*	139,945
	1	14,384	*17.0*	14,014	*14.2*	211	*11.5*	28,609
	2	5061	*6.0*	4670	*4.7*	53	*2.9*	9784
	≥ 3	3619	*4.3*	3015	*3.1*	45	*2.5*	6679
Stage	1	9235	*10.9*	18,915	*19.2*	379	*20.7*	28,529
	2	31,658	*37.4*	36,785	*37.3*	566	*30.8*	69,009
	3	28,999	*34.3*	31,967	*32.5*	648	*35.3*	61,614
	4	9494	*11.2*	6049	*6.1*	108	*5.9*	15,651
	Unknown	5283	*6.2*	4797	*4.9*	134	*7.3*	10,214
Study period	2007-2011	42,482	*50.2*	22,507	*22.9*	63	*3.4*	65,052
	2012-2016	26,794	*31.7*	36,927	*37.5*	306	*16.7*	64,027
	2017-2021	15,393	*18.2*	39,079	*39.7*	1466	*79.9*	55,938
YCR BCIP region	No	74,750	*88.3*	88,787	*90.1*	1653	*90.1*	165,190
	Yes	9919	*11.7*	9726	*9.9*	182	*9.9*	19,827

cancer. The highest percentage of MIS performed using robotic surgery in hospitals was 28.5% in colon cancer and 75.9% in rectal cancer (Supplemental Figure S1). Out of the 14 YCR BCIP hospitals, 4 hospitals were observed to be performing robotic surgery for colon cancer, and 5 hospitals were observed to be performing robotic surgery for rectal cancer.

Discussion

This study has shown a steady increase in the use of MIS for colorectal cancer patients undergoing an elective major resection in England, but with substantial variation across providers. Differences in the rate of uptake of MIS within England may be attributed to interpretation of national guidelines, the provision of surgical training and the availability of capital investment for relevant equipment. The national training plan (Programme for Laparoscopic Colorectal Cancer Surgery, LAPCO) was run at 11 national centres from 2006 to 2013,[18] providing one-to-one training by laparoscopic experts. The LAPCO Training the Trainer (LAPCO-TT) commenced in 2010 to improve the effectiveness of clinical training.[19] The number of surgeons attending these over the course of the study period and obtaining the necessary skills to provide laparoscopic surgery, will have impacted greatly on the uptake of MIS rates observed here. NICE guidelines will have influenced the uptake of MIS, and the need for a national training plan. Prior to the period covered by this study, guidelines in 2000 stated that open surgery should be the preferred procedure.[20] The guidelines were updated in 2006 to recommend laparoscopic surgery as an alternative to open resection for some patients by suitably trained surgeons and by those performing the procedure often enough to maintain competence.

Given the improvement in outcomes reported in Denmark,[21,22] a strategic approach of YCR BCIP was to compare management of Yorkshire's colorectal cancer population and benchmark that with those in Denmark. This study has shown MIS in Yorkshire now appears to be representative of MIS in England. However, by 2021, 80% of patients were receiving MIS in every England, still behind the Danish benchmark figure of greater than 90%. While Denmark did not employ a formal national laparoscopic-only training plan, several surgeons from 3 Danish regions attended individual and supervision by international experts in the UK. Subsequent training of surgeons was then conducted in Denmark. Danish guidelines initially issued the same conservative approach to the introduction of laparoscopic surgery; guidelines in 2009 recommend it should only be performed by surgeons with sufficient experience and volume. However, in 2014, laparoscopic surgery was recommended as the standard treatment for nonadvanced colon cancer and recommend for nonadvanced rectal cancer.[23] The DCCG have

Table 2 Characteristics for Patients With Rectal Cancer Undergoing Open, Laparoscopic and Robotic Surgery in England Diagnosed Between 2007 and 2021

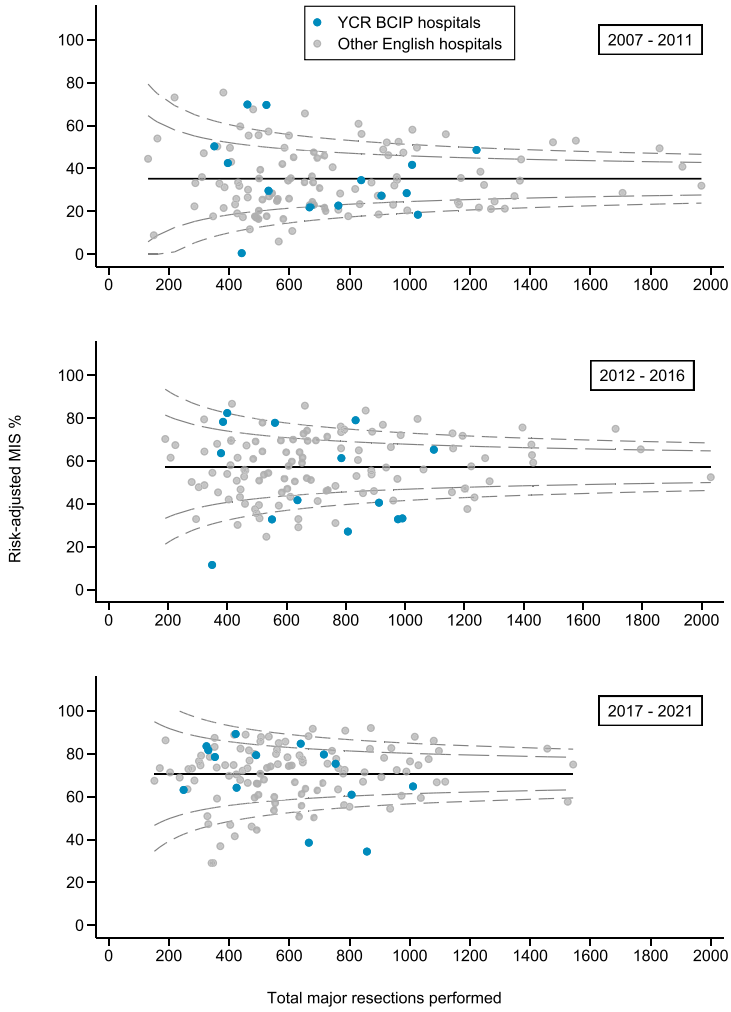
		Open		Laparoscopic		Robotic		Total
		N	%	N	%	N	%	
Total		34,560		32,317		2013		68,890
Age	18-59	8227	*23.8*	7839	*24.3*	528	*26.2*	16,594
	60-69	11,263	*32.6*	10,541	*32.6*	698	*34.7*	22,502
	70-79	10,811	*31.3*	10,092	*31.2*	601	*29.9*	21,504
	≥ 80	4259	*12.3*	3845	*11.9*	186	*9.2*	8290
Sex	Male	22,818	*66.0*	20,772	*64.3*	1355	*67.3*	44,945
	Female	11,742	*34.0*	11,545	*35.7*	658	*32.7*	23,945
IMD	1—least deprived	7248	*21.0*	6966	*21.6*	493	*24.5*	14,707
	2	7901	*22.9*	7386	*22.9*	424	*21.1*	15,711
	3	7221	*20.9*	7000	*21.7*	402	*20.0*	14,623
	4	6565	*19.0*	5918	*18.3*	356	*17.7*	12,839
	5—most deprived	5625	*16.3*	5047	*15.6*	338	*16.8*	11,010
CCI score	0	29,641	*85.8*	28,044	*86.8*	1764	*87.6*	59,449
	1	3482	*10.1*	2998	*9.3*	184	*9.1*	6664
	2	926	*2.7*	825	*2.6*	43	*2.1*	1794
	≥ 3	511	*1.5*	450	*1.4*	22	*1.1*	983
Stage	1	7285	*21.1*	8276	*25.6*	550	*27.3*	16,111
	2	8310	*24.1*	7815	*24.2*	445	*22.1*	16,570
	3	12,646	*36.6*	12,585	*38.9*	839	*41.7*	26,070
	4	2102	*6.1*	1524	*4.7*	83	*4.1*	3709
	Unknown	4217	*12.2*	2117	*6.6*	96	*4.8*	6430
Study period	2007-2011	18,172	*52.6*	7391	*22.9*	64	*3.2*	25,627
	2012-2016	11,151	*32.3*	12,897	*39.9*	537	*26.7*	24,585
	2017-2021	5237	*15.2*	12,029	*37.2*	1412	*70.1*	18,678
YCR BCIP region	No	30,302	*87.7*	28,759	*89.0*	1,822	*90.5*	60,883
	Yes	4258	*12.3*	3558	*11.0*	191	*9.5*	8007

also monitored the approach to surgery across the 5 Danish regions. Similar to England, annual reports observed regional differences in MIS uptake. This was most prominent in patients with colon cancer, in which 1 region had a much lower rate of MIS (50%) compared to other regions (range 75%-98%) in 2016.[12]

For interrogating data at set periods of time, the funnel plot methodology used in this study identified a number of potential outliers for use of laparoscopic surgery. However, we wished to identify trends for all hospitals (MDTs) within the YCRBCIP region, so extended the methodology to create "tunnel plots." This has the benefit of being a simple graphical presentation comparing patterns across multiple time periods, and helped show how hospitals are performing over that time. The data relating to MIS were presented and discussed with regional MDTs at programme events, annual reports and through individual meetings between the programme's surgical lead and a MDT representative as part of a wider data feedback schedule. While it was acknowledged that our analyses could not account for the all the differences experienced across the regional population, we aimed to identify potential sources of variation. Following feedback, a number of reasons for low rate of MIS were given: too few adequately trained surgeons, time pressures on available operating sessions (i.e. quicker to perform open surgery), patient selection in need of refinement and issues with regard to provision of modern laparoscopic equipment. Conversely, sharp upturns in rates of MIS coincided with recent appointments of laparoscopically trained surgeons. Following the start of the programme and regular feedback of data to surgical teams, the number of outlying hospitals in the region has reduced. Further work and monitoring will be needed to assess any potential influence the programme has had on MIS uptake in the region. This will also need to consider the impact of the COVID-19 pandemic and the debate around the safety of aerosol generating procedure and increased risk of viral transmission in healthcare workers.[24] The proportion of resections performed laparoscopically in England fell to 25% in the first wave of the pandemic under guideline issued at the time.[25]

In 2020, NICE guidelines included recommendations that robotic surgery in England should only be considered within established programmes that have appropriate audited outcomes. This was based on the reasoning that while clinical evidence suggested that there was no difference in effectiveness between laparoscopic and robotic techniques, robotic surgery was not found to be cost-effective at this time. This may impact on the uptake of robotic surgery equipment and training, as surgical departments not already

Figure 4 Funnel plots for adjusted minimally invasive surgery (MIS) percentage for patients with colorectal cancer in the English NHS.

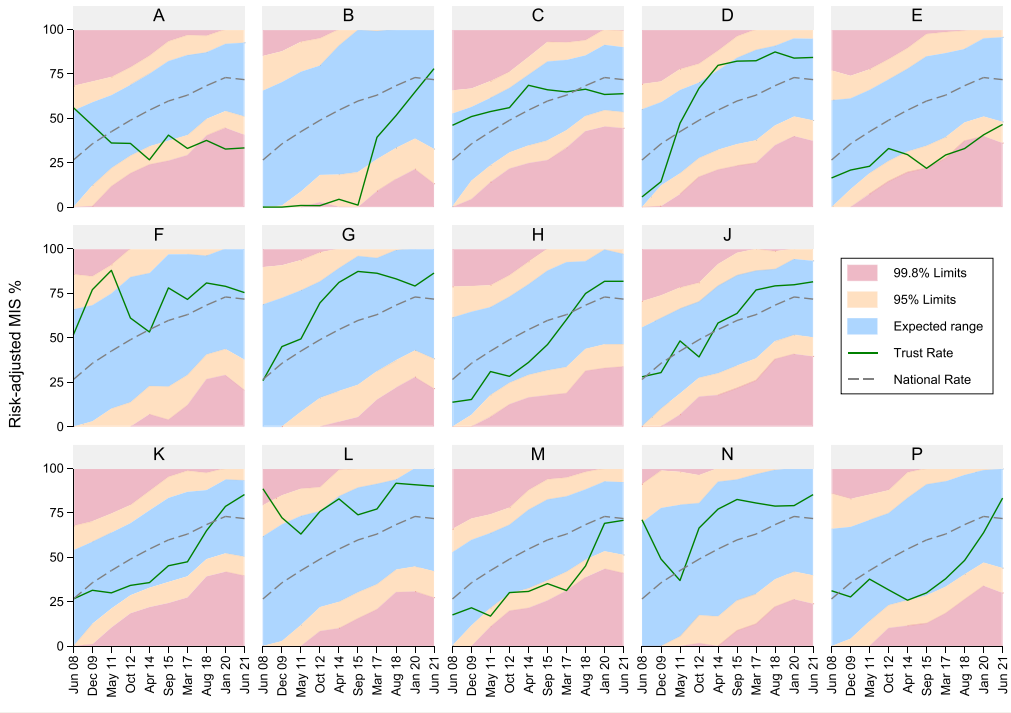


in possession of such equipment may have delayed investment until more evidence on its cost-effectiveness was gathered. A few years earlier, but with a similar conclusion, the DCCG formulated provisional guidelines in 2014 on robotic surgery for rectal cancer, stating that robot-assisted rectal surgery is equivalent to similar laparoscopic procedures in terms on short-term outcomes, with ongoing auditing and evaluation of short-term and long-term outcomes. While several studies from countries across the world have concluded robotic surgery for colorectal cancer resections is safe and outcomes are as at least equivalent of laparoscopic techniques, larger studies are needed to confirm its cost-effectiveness and long-term outcomes.[26-29]

Both regional and national variation in the uptake of robotic surgery may be driven by access to appropriate training programs. Around the time of this study, these have been predominantly provided by industry with the exception of a few and calls for a train-the-trainer curriculum were identified.[30] The successful introduction of robotic surgery may also depend upon sufficient support at a hospital and operation level, through provision of adequate funding, operating time and staffing.[31]

There are some limitations to this study that need to be considered when interpreting the results. Coding for MIS procedures in the hospital admission data used in the study was only introduced in 2006, so although rates are likely to be low for these years, it was not possible to confirm this. The years included rely on accurate data submission for MIS procedures and it is not possible to assess any changes in coding accuracy over that time. Several trials have reported noninferiority of single-port laparoscopic surgery when compared to multiport laparoscopic surgery in selected patients with colorectal cancer.[32-34] However, a further limitation of the coding meant that we could not investigate if there had been any uptake in single-port laparoscopic surgery. While use of the RCRD dataset provides more timely analysis of cancer data and enabled us to calculate rates of MIS more relevant to discussion with MDTs, this comes

Figure 5 Tunnel plots for adjusted minimally invasive surgery (MIS) percentage for patients with colorectal cancer diagnosed between 2007 and 2021 at each hospital (A-P) in the Yorkshire (YCR BCIP) region.



at a cost in data quality. When compared to diagnoses used for the gold-standard cancer registry, the RCRD had a false negative rate of near to 10% and a false positive rate < 5%.[35] Completeness of tumour staging is also lower in the RCRD than in the cancer registry (22% v 9% unknown stage), but agreement of those who are staged is 85%-93%. While only 1 year on overlap was available for our study, the annual MIS rate in the RCRD was slightly higher (1.3%) than in the NCRAS dataset.

A direct comparison on the patient characteristics between England, Yorkshire and Denmark, would give more insight into the populations undergoing MIS and whether the higher rates observed in Denmark could be attributed to a greater suitability of those selected for MIS. Previous studies have shown similarities between the basic patient characteristics, disease burden and life expectancies,[36-38] but it should be noted that both per capita healthcare spending and the relative number of doctors and nurses per person are both higher in Denmark than the UK.[39]

This study has found wide variation in the use of MIS exists in the English NHS and a data-driven approach has helped identify outlying hospitals (MDTs) for a regional improvement programme, and further monitoring of the results presented here over the following years will help to assess the impact of the programme. Addressing some of the challenges behind the provision of MIS, such as ensuring adequate provision of surgical training, and provision of modern state-of-the-art equipment, could help increase the number of suitable patients selected for elective MIS and the associated benefit of improved postoperative recovery.

Clinical Practice Points

- Minimally invasive surgery for colorectal cancer is as effective as open surgery but has the potential to improve recovery time, but its uptake varies between countries.
- We found uptake of laparoscopic and robotic surgery in England was slower than that in Denmark and found significant variation in rates of minimally invasive surgery at the hospital level.
- The reasons identified for low uptake of minimally invasive surgery included too few adequately trained surgeons and lack of modern laparoscopic equipment.
- Through a quality improvement programme we have demonstrated a reproducible methodology to identify outlying hospitals and the areas to focus on for improving provision of minimally invasive surgery.

Disclosure

The authors declare there are no conflicts of interest.

CRediT authorship contribution statement

John C. Taylor: Conceptualization, Methodology, Formal analysis, Writing – original draft, Visualization. **Dermot Burke:** Supervision, Writing – review & editing. **Lene H. Iversen:** Conceptualization, Resources, Data curation, Writing – review & editing. **Rebecca J. Birch:** Formal analysis, Data curation. **Paul J. Finan:** Investigation, Writing – review & editing. **Mark M. Iles:** Super-

vision, Writing – review & editing. **Philip Quirke:** Conceptualization, Supervision, Funding acquisition, Writing – review & editing. **Eva J.A. Morris:** Conceptualization, Resources, Supervision, Funding acquisition, Writing – review & editing.

Data Availability Statement

The data used for this study are available from the National Cancer Registration and Analysis Service via application to NHS England or CORECT-R.

Ethical Approval

The study was granted ethical approval (17/WM/0374) by the West Midlands - Solihull Research Ethics Committee in December 2017. The study was approved by the Health Research Authority and granted approval for inclusion in the National Institute for Health Research's portfolio of studies in December 2017 (Project ID 227673).

Acknowledgments

This work uses data that has been provided by patients and collected by the NHS as part of their care and support. 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. Access to the data was facilitated by the Office for Data Release and the Cancer Research UK funded UK Colorectal Cancer Intelligence Hub (C23434/A23706). We thank the Danish Colorectal Cancer Group (DCCG) the provision of published Danish data presented in this study.

The Yorkshire Cancer Research Bowel Cancer Improvement Programme (YCR BCIP) study group includes Philip Quirke, Eva Morris, Paul Finan, Nicholas West, Kate Absolom, Daniel Swinson, Damian Tolan, Simon Howell, James Turvill, Sarah Alderson, John Taylor, Amy Glover, Hannah Rossington, Emily Boldison, Barbara Hibbert and Kate Bartholomew. The YCR BCIP research team acknowledges the support of the National Institute for Health Research Clinical Research Network (NIHR CRN). This work was funded by Yorkshire Cancer Research (Award reference number L394). Prof Quirke holds an NIHR Senior Investigator award. Mark Iles is supported in part by the National Institute for Health and Care Research (NIHR) Leeds Biomedical Research Centre. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health and Social Care. The UK Colorectal Cancer Intelligence Hub is supported by the Bobby Moore Fund/Cancer Research UK (C23434/A23706).

References

1. Jacobs M, Verdeja JC, Goldstein HS. Minimally invasive colon resection (laparoscopic colectomy). *Surg Laparosc Endosc*. 1991;1:144–150.
2. Guillou PJ, Quirke P, Thorpe H, et al. Short-term endpoints of conventional versus laparoscopic-assisted surgery in patients with colorectal cancer (MRC CLASICC trial): multicentre, randomised controlled trial. *Lancet*. 2005;365:1718–1726.
3. Kennedy RH, Francis EA, Wharton R, et al. Multicenter randomized controlled trial of conventional versus laparoscopic surgery for colorectal cancer within an enhanced recovery programme: EnROL. *J Clin Oncol*. 2014;32:1804–1811.
4. van der Pas MH, Haglind E, Cuesta MA, et al. Laparoscopic versus open surgery for rectal cancer (COLOR II): short-term outcomes of a randomised, phase 3 trial. *Lancet Oncol*. 2013;14:210–218.
5. National institute for health and care excellence (NICE). *Colorectal cancer: diagnosis and management*. London: National Institute for Health and Care Excellence; 2011.
6. Ishiyama Y, Tachimori Y, Harada T, et al. Oncologic outcomes after laparoscopic versus open multivisceral resection for local advanced colorectal cancer: A meta–analysis. *Asian J Surg*. 2023;46:6–12.
7. Kolfschoten NE, van Leersum NJ, Gooiker GA, et al. Successful and safe introduction of laparoscopic colorectal cancer surgery in Dutch hospitals. *Ann Surg*. 2013;257:916–921.
8. Li K, Pang P, Cheng H, et al. Protective effect of laparoscopic functional total mesorectal excision on urinary and sexual functions in male patients with mid-low rectal cancer. *Asian J Surg*. 2023;46:236–243.
9. Volkel V, Draeger T, Gerken M, Klinkhammer-Schalke M, Furst A. Long-term oncologic outcomes after laparoscopic vs. open colon cancer resection: a high-quality population-based analysis in a Southern German district. *Surg Endosc*. 2018;32:4138–4147.
10. Warps AK, Saraste D, Westerterp M, et al. National differences in implementation of minimally invasive surgery for colorectal cancer and the influence on short-term outcomes. *Surg Endosc*. 2022;36:5986–6001.
11. Babaei M, Balavarca Y, Jansen L, et al. Minimally invasive colorectal cancer surgery in Europe: implementation and outcomes. *Medicine (Baltimore)*. 2016;95:e3812.
12. Danish Colorectal Cancer Group. Annual Report 2016. Available at: https://www.dccg.dk. Accessed January 25, 2023.
13. Taylor J, Wright P, Rossington H, et al. Regional multidisciplinary team intervention programme to improve colorectal cancer outcomes: study protocol for the Yorkshire Cancer Research Bowel Cancer Improvement Programme (YCR BCIP). *BMJ Open*. 2019;9:e030618.
14. Downing A, Hall P, Birch R, et al. Data resource profile: The COloRECTal cancer data repository (CORECT-R). *Int J Epidemiol*. 2021;50:1418 1418k.
15. Taylor JC, Swinson D, Seligmann JF, et al. Addressing the variation in adjuvant chemotherapy treatment for colorectal cancer: can a regional intervention promote national change? *Int J Cancer*. 2021;148:845–856.
16. Ingeholm P, Gogenur I, Iversen LH. Danish colorectal cancer group database. *Clin Epidemiol*. 2016;8:465–468.
17. Spiegelhalter DJ. Funnel plots for comparing institutional performance. *Stat Med*. 2005;24:1185–1202.
18. Coleman MG, Hanna GB, Kennedy R. National Training Programme (Lapco). The national training programme for laparoscopic colorectal surgery in England: a new training paradigm. *Colorectal Dis*. 2011;13:614–616.
19. Mackenzie H, Cuming T, Miskovic D, et al. Design, delivery, and validation of a trainer curriculum for the national laparoscopic colorectal training program in England. *Ann Surg*. 2015;261:149–156.
20. Green CJ, Maxwell R, Verne J, Martin RM, Blazeby JM. The influence of NICE guidance on the uptake of laparoscopic surgery for colorectal cancer. *J Public Health*. 2009;31:541–545.
21. Iversen LH. Aspects of survival from colorectal cancer in Denmark. *Dan Med J*. 2012;59:B4428.
22. Iversen LH, Ingeholm P, Gogenur I, Laurberg S. Major reduction in 30-day mortality after elective colorectal cancer surgery: a nationwide population-based study in Denmark 2001-2011. *Ann Surg Oncol*. 2014;21:2267–2273.
23. *DCCG National Guidelines for Colorectal Cancer Diagnosis and Treatment: Laparoscopic Colon Surgery*. Denmark: Danish Colorectal Cancer Group; 2014.
24. El Boghdady M, Ewalds-Kvist BM. Laparoscopic Surgery and the debate on its safety during COVID-19 pandemic: a systematic review of recommendations. *Surg*. 2021;19:e29–e39.
25. Morris EJA, Goldacre R, Spata E, et al. Impact of the COVID-19 pandemic on the detection and management of colorectal cancer in England: a population-based study. *Lancet Gastroenterol Hepatol*. 2021;6:199–208.
26. Pan J, Wang B, Feng Z, et al. Robotic versus laparoscopic total mesorectal excision for mid-low rectal cancer with difficult anatomical conditions. *Asian J Surg*. 2022;45:2725–2732.
27. Wei PL, Huang YJ, Wang W, Huang YM. Comparison of robotic reduced-port and laparoscopic approaches for left-sided colorectal cancer surgery. *Asian J Surg*. 2023;46:698–704.
28. Pai A, Marecik SJ, Park JJ, Melich G, Sulo S, Prasad LM. Oncologic and clinicopathologic outcomes of robot-assisted total mesorectal excision for rectal cancer. *Dis Colon Rectum*. 2015;58:659–667.
29. Ramji KM, Cleghorn MC, Josse JM, et al. Comparison of clinical and economic outcomes between robotic, laparoscopic, and open rectal cancer surgery: early experience at a tertiary care center. *Surg Endosc*. 2016;30:1337–1343.
30. Gomez Ruiz M, Alfieri S, Becker T, et al. Expert consensus on a train-the-trainer curriculum for robotic colorectal surgery. *Colorectal Dis*. 2019;21:903–908.
31. Randell R, Honey S, Alvarado N, et al. Factors supporting and constraining the implementation of robot-assisted surgery: a realist interview study. *BMJ Open*. 2019;9:e028635.
32. Lee YS, Kim JH, Kim HJ, et al. Short-term outcomes of single-port versus multiport laparoscopic surgery for colon cancer: the SIMPLE multicenter randomized clinical trial. *Ann Surg*. 2021;273:217–223.
33. Tang J, Yang J, Yang JS, et al. Stoma-site approach single-port laparoscopic versus conventional multi-port laparoscopic Miles's procedure for low rectal cancer: a prospective, randomized controlled trial. *Asian J Surg*. 2023;46:4317–4322.
34. Watanabe J, Ota M, Fujii S, Suwa H, Ishibe A, Endo I. Randomized clinical trial of single-incision versus multiport laparoscopic colectomy. *Br J Surg*. 2016;103:1276–1281.

35. *NDRS Rapid Cancer Registration Dataset (RCRD) Data Quality Document*. Leeds: NHS-Digital; 2022.
36. Taylor JC, Iversen LH, Burke D, et al. Influence of age on surgical treatment and postoperative outcomes of patients with colorectal cancer in Denmark and Yorkshire, England. *Colorectal Dis*. 2021;23:3152–3161.
37. Taylor JC, Iversen LH, Burke D, et al. Differences in the management of patients requiring an emergency resection for colonic cancer in two European populations. *BJS Open*. 2022;6:zrac126.
38. Access GBDH, Quality Collaborators. Electronic address cue, access GBDH, quality C. Healthcare access and quality index based on mortality from causes amenable to personal health care in 195 countries and territories, 1990-2015: a novel analysis from the Global Burden of Disease Study 2015. *Lancet*. 2017;390:231–266.
39. Papanicolas I, Woskie LR, Jha AK. Health care spending in the United States and other high-income countries. *JAMA*. 2018;319:1024–1039.

Supplementary Material

Supplementary Table S1 Percentage of resection preformed using open, laparoscopic and robotic surgery in YCR BCIP and England for patients with colorectal cancer diagnosed between 2007 and 2021.

		Colon			Rectal		
		Open	Laparoscopic	Robotic	Open	Laparoscopic	Robotic
YCR BCIP	2007–2011	66.9	33.0	0.2	69.0	30.4	0.6
	2012–2016	49.2	50.2	0.6	51.4	46.1	2.5
	2017–2021	30.9	66.9	2.1	32.7	62.6	4.7
England	2007–2011	65.1	34.8	0.1	71.2	28.6	0.2
	2012–2016	41.0	58.6	0.5	44.5	53.3	2.1
	2017–2021	27.1	70.2	2.7	27.5	64.6	7.9
Difference	2007–2011	+1.7	-1.8	+0.1	-2.2	+1.8	+0.4
	2012–2016	+8.2	-8.4	+0.2	+6.9	-7.3	+0.4
	2017–2021	+3.8	-3.3	-0.5	+5.2	-2.0	-3.2

Supplementary Figure S1 Hospital variation in percentage of minimally invasive surgery performed robotically in patients with colorectal cancer diagnosed between 2017 and 2021. Hospitals within the YCR BCIP region and performing robotic surgery are labelled A to P.