



Standardised approach to laparoscopic total mesorectal excision for rectal cancer: a prospective multi-centre analysis

Marc Bullock¹ · Irfan Ul Islam Nasir² · Anil Hemandas³ · Tahseen Qureshi⁴ · Nuno Figueiredo² · Richard Heald² · Amjad Parvaiz^{2,4,5}

Received: 22 April 2019 / Accepted: 16 July 2019 / Published online: 3 August 2019
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

Abstract

Purpose Two non-inferiority randomised control trials have questioned the utility of laparoscopic surgery for rectal cancer by failing to prove that pathological markers of high-quality surgery are equivalent to those achieved by open technique. We present short- and long-term post-operative outcomes from the largest single surgeon series of consecutive patients undergoing laparoscopic TME for rectal cancer. We describe the standardised laparoscopic technique developed by the principal surgeon, and the short-term outcomes from three surgeons who were trained in and subsequently adopted the same approach.

Methods Prospectively acquired data from consecutive patients undergoing surgery for rectal cancer by the principal surgeon at the minimally invasive colorectal unit in Portsmouth between 2006 and 2014 were analysed along with data acquired between 2010 and 2017 from surgeons at three further international centres. Endpoints were overall and disease-free survival at 5 years, and early post-operative clinical and pathological outcomes.

Results Two hundred sixty-three consecutive patients underwent laparoscopic TME surgery by the principal surgeon. At 5 years, overall survival was 82.9% (Dukes' A = 94.4%; B = 81.6%; C = 73.7%); disease-free survival was 84.0% (Dukes' A = 93.3%; B = 86.8%; C = 72.6%). Post-operative length of stay, lymph node harvest, mean operating time, rate of conversion, major morbidity and 30-day mortality were not significantly different between the principal surgeon and those he had trained when subsequently in independent practices.

Conclusion Laparoscopic TME produces excellent long-term survival outcomes for patients with rectal cancer. A standardised approach has the potential to improve outcomes by setting benchmarks for surgical quality, and providing a step-by-step method for surgical training.

Keywords TME · Total mesorectal excision · Rectal cancer · Laparoscopic surgery · Standardisation

Introduction

Total mesorectal excision (TME) by careful delineation and removal of the intact visceral mesentery of the rectum has been accepted as the most important contributor to improved rates of local recurrence (LR), overall survival (OS) and disease-free survival (DFS) [1, 2] in rectal cancer.

TME was initially described as an open procedure [3] but perceived improvements in short-term outcomes and post-operative recovery resulted in wide-spread uptake of the laparoscopic technique [4]. Early randomised control trial (RCT) data suggested at the very least there was equivalence in terms of oncological outcomes between the two approaches [5]. In sub-group analysis, the COLOR II trial identified a potential survival benefit for laparoscopic surgery in more advanced (stage III) disease [6], whereas large-scale retrospective

✉ Amjad Parvaiz
apcheema@yahoo.com

¹ Department of Academic Surgery, University Hospital Southampton, Southampton, UK

² Laparoscopic and Robotic Colorectal Unit, Fundação Champalimaud, Lisbon, Portugal

³ Department of Colorectal Surgery, Milton Keynes University Hospital NHS Foundation Trust, Milton Keynes, UK

⁴ Department of Minimal Invasive Colorectal Surgery, Poole Hospital NHS Foundation Trust, Long fleet Road, Poole, Dorset BH15 2JB, UK

⁵ Faculty of Health Sciences, University of Portsmouth, Portsmouth, UK

analyses based on comprehensive cancer registry data have identified superior resection margins and rates of disease-free local recurrence compared with open surgery [7, 8].

Of the four major RCTs to have examined the issue, those which used LR or survival as outcome measures (COLOR II and COREAN trials) [6, 9] both concluded that laparoscopic surgery is equivalent to open surgery, whereas two studies which used pathological markers of surgical quality (ALaCart and ACOSOG) [10, 11], such as the circumferential resection margin (CRM) and completeness of TME as a primary end-point, concluded that ‘non-inferiority’ of laparoscopic surgery has not been established.

Allowing for differences in patient selection and the limitations of ‘non-inferiority’ study design [12], the tension between these prospective but relatively narrow RCT analyses and ‘real-world’ but retrospective observational studies has introduced uncertainty regarding the utility of minimally invasive surgery (MIS) techniques in rectal cancer surgery and, although widely practised, laparoscopic TME remains especially controversial [13]. By the same token, the merit of using surrogate outcome measures rather than measures which directly reflect the length and quality of patient’s lives has become hotly contested [14].

The major criticism of laparoscopic surgery in this context is that laparoscopic instruments which are mostly long and straight are less ergonomic than the surgeon’s wrist and may exacerbate a ‘coning’ effect which compromises the TME plane at the approach to the pelvic floor. The acute forward angulation of the sacrum combined with the distal lateral expansions of the mesorectal envelope poses a particular challenge for such instruments, which have limited articulation at their tips. This may in turn lead to increased rates of CRM positivity and incomplete mesorectal excision, both of which have a direct bearing on oncological outcome and in particular, the rates of LR [15, 16].

Recent meta-analysis of 14 RCTs identified a trend towards increased CRM involvement (7.9% vs 6.1%) and incomplete excision (13.2% vs 10.4%) in laparoscopic vs. open surgery [13], highlighting the technical challenge of operating within the confines of the pelvis, and a potential niche for evolving techniques such as robotic surgery [17] and trans-anal TME [18].

The counter argument in support of laparoscopic surgery recognises that the impact of CRM involvement on long-term oncological and survival outcomes is uncertain. For example, trial data showing almost twice the rate of CRM positivity for laparoscopic compared with open TME subsequently identified no significant differences in OS, DFS, or LR between the groups at 10 years (MRC CLASSIC trial) [5, 19]. To confuse matters further, a large retrospective analysis of 16,619 patients with stages I–III rectal cancer demonstrated significantly lower rates of CRM involvement in laparoscopic compared with open TME (14.9% vs 18.1%) [20].

Given renewed scrutiny of the laparoscopic approach, the contribution of factors such as standardisation and quality of training, and the variation in outcomes between individual surgeons have become increasingly topical. Here we present what we believe to be the largest single operator series of consecutive laparoscopic TME operations to date. We illustrate how the principles of open TME surgery may be adapted into a systematic laparoscopic method without compromising long-term survival outcomes. This study also examines the generalisation of this technique as after undergoing standardised and structured training, three further international centres demonstrate that laparoscopic TME can be performed safely and effectively using a standardised approach.

Material and methods

Between 13 October 2006 and 14 November 2014, 263 consecutive patients diagnosed with adenocarcinoma of the rectum underwent surgery at the minimally invasive colorectal unit at the Queen Alexandra Hospital (QAH) in Portsmouth. Patients treated with both curative and palliative intent are considered in this analysis. Local ethical approval was sought and patients provided informed consent to be included in the study.

Surgery was performed by a single surgeon (AP) but more than 90% of cases included the training of junior surgeons. Three surgeons who worked as Training Fellows under the supervision of the primary surgeon for 12 months or more went on to incorporate the detailed routines into their independent practices at Poole Hospital NHS Foundation Trust (TQ) and Milton Keynes University Hospital Foundation Trust (AH) in the UK, and Fundação Champalimaud in Lisbon, Portugal (NF). Between 10 August 2010 and 17 July 2017, they performed a further 116 laparoscopic TME operations using the systematic operative approach developed at QAH and described below.

Treatment intent was determined preoperatively based on magnetic resonance imaging (MR) of the rectum and the presence and resectability of lung or liver metastases on computed tomography (CT).

All patients were discussed at a specialist multi-disciplinary team meeting (MDT). Standard diagnostic and staging investigations included colonoscopy, pelvic MR, high-resolution CT of the chest and abdomen and endoanal ultrasound for ultra-low tumours.

Preoperative chemo-radiotherapy (CRT) was restricted to patients with T4 lesions, or T3 with threatened/involved mesorectal fascia, or N2 or extramesorectal involved lymph nodes on MR. Tumours were identified as high, middle, or low based on proximity to the anal verge (10.1–15 cm; 5.1–10 cm and < 5 cm, respectively) measured using MR. Each operation was performed laparoscopically and incorporated a

standardised TME procedure. Operations included anterior resection (AR), abdominoperineal resection (APER), Hartmann's procedure and panproctocolectomy.

Temporary ileostomies were performed in an unselected manner for all patients undergoing AR for low or mid-rectal tumours.

Major complications included reoperation, anastomotic leak (AL) and readmission to the hospital within 30 days. AL was defined as a leak sufficient to cause symptoms, confirmed by radiology (high-resolution CT) and requiring either radiological or surgical intervention. Complications were further classified according to the Clavien-Dindo (CD) scale [21].

Conversion was defined as any incision made to either facilitate dissection of specimen or to take vascular control. The extraction site was utilised only to extract the specimen.

Recurrence was defined as any radiological or histological evidence of tumour re-growth at or near the primary site of surgery. The presence of distant metastases was also documented.

Operative method

Patient preparation

- Operative risk assessment by anaesthetist in an outpatient setting
- Mechanical bowel preparation for all patients undergoing resection with low anastomosis
- Modified enhanced recovery program as popularised by Henrik Kehlet in all cases [22]
- Single-shot spinal analgesia for pain relief in first 24 h
- Patients marked preoperatively for loop ileostomy or end colostomy by stoma nurse
- Informed consent signed by patient

Positioning and setup

- Modified Lloyd-Davis position
- A vacuum bean bag used to prevent on-table movement in extreme tilt
- Sequential compression devices to lower extremities
- Prophylactic single-shot antibiotic administered prior to the start of operation
- Digital rectal examination (DRE)
- Operating surgeon, assistants, scrub nurse and high-definition monitors positioned as per Fig. 1

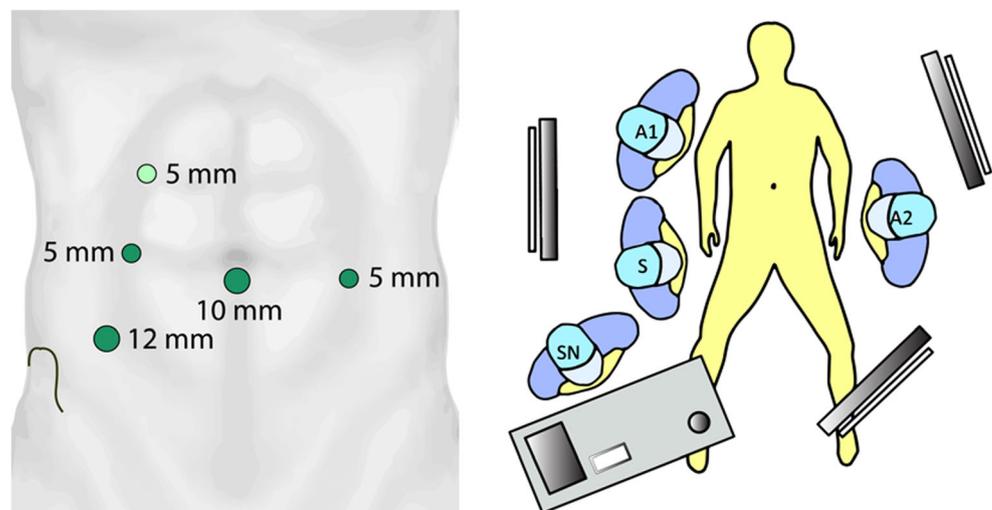
Port placement

- Modified Hasson infra-umbilical port entry. Ten-millimetre port admits 30-degree laparoscope
- Further ports placed under direct vision as per Fig. 1

Colonic mobilisation

- Patient brought head-down (Trendelenburg position) with right tilt of table, to empty pelvis of small bowel
- Sigmoid mesentery exposed. Medial to lateral dissection performed as previously described [23]
- Inferior mesenteric artery clipped 1–2 cm from origin sparing preaortic autonomic nerves; inferior mesenteric vein divided at lower border of the pancreas
- Lateral colonic mobilisation and completion of splenic flexure mobilisation were effected with monopolar diathermy ± ligasure (Covidien-Medtronic; MN, USA) or Harmonic® scalpel (Ethicon; NJ, USA).

Fig. 1 Standard theatre setup and port positioning for laparoscopic TME. Surgeon (S), assistant (A), scrub nurse (SN)



Pelvic dissection

- The 7 key steps involved in the pelvic TME dissection include ‘entering the posterior TME plane’; ‘developing the anterior TME plane’; ‘anterior dissection’; ‘lateral dissection to the pelvic floor’; ‘posterior completion’; ‘anterior completion’; and ‘transection and anastomosis’.
- For the pelvic dissection, we consider traction, counter traction and monopolar diathermy essential. Gauze tonsil swabs gently open the two fascial layers between the visceral envelope and surrounding parietes without tearing the surfaces. Progress is achieved only in the white avascular tissue with sharp monopolar diathermy dissection in the innermost dissectible plane, as described by Heald et al. [2]. The use of the monopolar diathermy ‘hook’ has the advantage of most effectively putting the areolar tissues on stretch which reduces the charring and also cuts most precisely.
- The posterior rectal dissection specifically dissects anterior to and within Waldeyer’s fascia, which ensures a dry avascular plane and avoids presacral venous bleeding. It sets the scene for extension laterally and then anterior to Denonvilliers’ septum which must ultimately be incised distally in a U-shape; the whole peritoneal reflection and most of Denonvilliers’ being excised with the specimen. Otherwise, all dissection is performed between the visceral mesorectal fascia and the fascia lining the retroperitoneum and the pelvic sidewalls, with sharp division of the small nerves and diathermy of vessels at the points of adherence previously called the ‘lateral ligaments’.
- The TME is completed at the pelvic floor. The ano-coccygeal ligament (pubo-coccygeus) is divided posteriorly in the ultra-low cases to complete exposure of the ano-rectal muscle tube for precise division and anastomosis.
- The tumour height is assessed by digital rectal exam (DRE), the rectum clamped proximally and the lumen washed-out with aqueous betadine. Upward traction on a special clamp facilitates application of stapler very low down.
- The rectum is divided with two (maximally three) firings of Endo-GIA® 45 mm stapler (Covidien; MN, USA).

Specimen extraction and anastomosis

- Specimen extraction through 5 cm incision using Alexis® (Applied Medical; CA, USA) wound protector self-retractor.
- Colorectal anastomosis formed with 29 mm CDH (Ethicon; NJ, USA) stapling device (AR) or the CEEA 29 (Covidien – Medtronic; MN, USA)

- Anastomosis is tested with flexible endoscope to confirm that there is no bleeding and gas insufflation under water confirms no leak.
- Colo-anal hand sewn anastomosis is preferred for tumours actually at the dentate line.

Statistical analysis

Analysis of clinicopathological patient data was performed using a combination of independent *t* tests, χ^2 and Pearson’s correlation tests. Disease-free survival and overall survival were analysed using Kaplan–Meier survival curves with log-rank tests for significance. A threshold level of significance was set at 0.05 for all statistical tests in this study, and all statistical analyses were performed using SPSS® version 22 (SPSS, IBM, Chicago, IL, USA).

Results

Patient demographics, early post-operative outcomes and complications

Over an 8 year period, 263 consecutive patients underwent laparoscopic TME for rectal adenocarcinoma by a single surgeon at the minimally invasive surgical unit at the QAH in Portsmouth. Of these, 231 were treated with curative intent (87.8%). Patient and tumour characteristics are summarised in Table 1.

Two hundred and eighteen patients (82.9%) underwent a sphincter-preserving resection with primary anastomosis (AR), of which 200 were performed with curative intent and 189 were defunctioned with a stoma. Reconstitution of enteric continuity was performed at a median 7.52 (range 0.72–31.05) months following the index procedure.

Out of the 263 patients operated by AP, approximately a quarter of tumours were located low (24%; $n = 63$) or high (25.5%; $n = 67$) in the rectum and approximately half in the mid-rectum (50.6%; $n = 133$).

For all patients undergoing surgery, the 30-day mortality was 0.76% with two deaths in the immediate post-operative period from cardiac complications following APER. Mortality after sphincter-preserving surgery was zero. The 30-day reoperation rate was 2.3% ($n = 6$) and the 30-day readmission rate 16.0% ($n = 42$).

Overall, 1.5% ($n = 4$) operations were converted from laparoscopic to open surgery for the following reasons: technical ($n = 1$); oncological ($n = 2$); morbid obesity ($n = 1$). One operation was converted to an open approach as the patient was intolerant of pneumoperitoneum in the reverse Trendelenburg position under general anaesthetic.

Table 1 Patient and tumour demographic data

	AP (<i>n</i> = 263)	TQ/AH/NF (<i>n</i> = 116)	<i>P</i> value
Mean age in years (s.d)	66.94 (11.30)	65.84 (10.17)	0.16 ^a
Gender (M:F)	167:96	68:48	0.37 ^b
ASA % (<i>n</i>)			0.98 ^b
I	10.6 (28)	11.2 (13)	
II	66.2 (174)	67.2 (78)	
III	20.9 (55)	19.8 (23)	
Data missing	2.3 (6)	1.7 (2)	
BMI % (<i>n</i>)			0.00 ^b
Underweight	1.5 (4)	0	
Good	29.3 (77)	31.9 (37)	
Overweight	41.4 (109)	37.9 (44)	
Obese	26.6 (70)	16.4 (19)	
Data missing	1.1 (3)	13.8 (16)	
Radiotherapy % (<i>n</i>)			0.00 ^b
None	77.6 (204)	73.3 (85)	
Neo-adjuvant short course	6.8 (18)	0	
Neo-adjuvant long course	14.4 (38)	26.7 (31)	
Post-operative	0.4 (1)	0	
Data missing	0.8 (2)	0	
Procedure name % (<i>n</i>)			0.32 ^b
AR	82.9 (218)	83.6 (97)	
APER	13.7 (36)	12.9 (15)	
Hartmann's	1.1 (3)	0.9 (1)	
Panproctocolectomy	2.3 (6)	2.6 (3)	
T stage % (<i>n</i>)			0.00 ^b
ypT0	0	9.5 (11)	
1	24.2 (37)	11.2 (13)	
2	31.9 (84)	36.2 (42)	
3	47.9 (126)	38.8 (45)	
4	4.9 (13)	4.8 (5)	
Data missing	1.1 (3)	0	
N stage % (<i>n</i>)			0.00 ^b
ypTN0	0	6.9 (8)	
0	62.7 (165)	64.7 (75)	
1	25.1 (66)	18.1 (21)	
2	11.0 (29)	10.3(12)	
Data missing	1.1 (3)	0	
Dukes' stage			0.00 ^b
Pathological complete response	0	8.8 (10)	
A	34.2 (90)	36.0 (41)	
B	28.9 (76)	27.2 (31)	
C	36.1 (95)	28.1 (32)	
Data missing	0.8 (2)	0	

^aIndependent *t* test; ^bPearson correlation; ^c χ^2 test

A total of six (2.3%) patients undergoing AR developed AL requiring surgical re-intervention.

7.2% (*n* = 19) of patients had complications requiring admission to intensive care, or a surgical or radiological

intervention in the immediate post-operative period (CD III and IV) and 19.4% (*n* = 51) of patients were classified as having peri operative complications within 30 days.

Extending our analysis to include 116 consecutive TME operations performed by three surgeons who had adopted an identical laparoscopic approach following a period of training at the QAH hospital in Portsmouth, we found no significant differences in early post-operative outcomes or complications compared with the Portsmouth dataset. This included length of stay, rate of conversion to open surgery, operating time and 30-day mortality (Table 2).

Pathological outcomes

In the Portsmouth cohort, the resection margin (CRM) was infiltrated by microscopic tumour deposits (R1 resection) in 9 cases overall (3.4%) and the mean LN harvest was 15.65 (S.D 8.40).

Overall, local recurrence (LR) was identified in 1.1% ($n = 3$) of patients, all of whom had undergone AR. Local recurrence occurred at a mean of 15.39 (range 8.97–18.82) months following surgery. Two of the three patients with LR had post-operative anastomotic leaks managed conservatively; all three patients had ‘early’ Dukes’ A or B tumours; all were histologically complete (R0) resections and none had undergone neo-adjuvant therapy.

In the Poole/Lisbon/Milton Keynes dataset, the R1 resection rate was not significantly different from Portsmouth and the median number of LN resected per specimen was marginally greater (Table 2).

Patterns of tumour recurrence and long-term outcomes

Median follow-up for patients undergoing laparoscopic TME in Portsmouth was 45.17 months (range 0.16–100.83) and 26.76 months (range 2.20–82.30) in Poole, Lisbon and Milton Keynes. For all those undergoing laparoscopic TME at the QAH hospital, OS at 5 years was 82.9% (Dukes’ A = 94.4%; Dukes’ B = 81.6%; Dukes’ C = 73.7%) (Fig. 2a); and DFS was 84.0% (Dukes’ A = 93.3%; Dukes’ B = 86.8%; Dukes’ C = 72.6%) (Fig. 2b). Distant metastasis was observed in 42 patients during the course of follow-up, reflecting an

overall rate of distal recurrence equivalent to 6.7% for Dukes’ A tumours, 13.2% for Dukes’ B tumours and 27.4% for Dukes’ C tumours, respectively.

Relatively short follow-up in the Poole/Lisbon/Milton Keynes cohort precludes meaningful analysis of OS, DFS and LR.

Discussion

These data are presented at this time because the status of laparoscopic surgery in rectal cancer has been questioned by the ‘non-inferiority’ studies cited above. Other data demonstrate that the quality of rectal cancer surgery is still highly variable between centres [19, 20, 24, 25]. These factors have renewed interest in operative standardisation and the teaching of operative technique for TME surgery [23, 26–28], which is timely as we consider what may be achieved by a single surgeon or by small disciplined groups of surgeons with one standardised stepwise technique may be a fairer test for the potential of any new technology.

The data presented here report the largest single surgeon series of consecutive minimally invasive rectal cancer operations published to date. DFS, OS and LR rates for unselected patients undergoing laparoscopic TME resections, including those treated with palliative intent, was 84.0%, 82.9% and 1.1%, respectively. For the purpose of comparison, a Cochrane review of RCTs of laparoscopic vs. open TME surgery involving 3528 patients identified in the laparoscopic arm that DFS and OS rates at 5 years were approximately 72.2% and 70.9% respectively, with LRs occurring in 4.8% of cases; and 71.8% and 67.9%, respectively in the open arm, with local recurrences occurring in 5.4% of cases [4]. Comparable case series published in the literature describe patient cohorts which vary from 174 to 226 patients in size and report 5-year DFS rates between 61.9 and 71%; OS rates between 74 and 81% and LR rates between 3.4 and 6.1% [29–31].

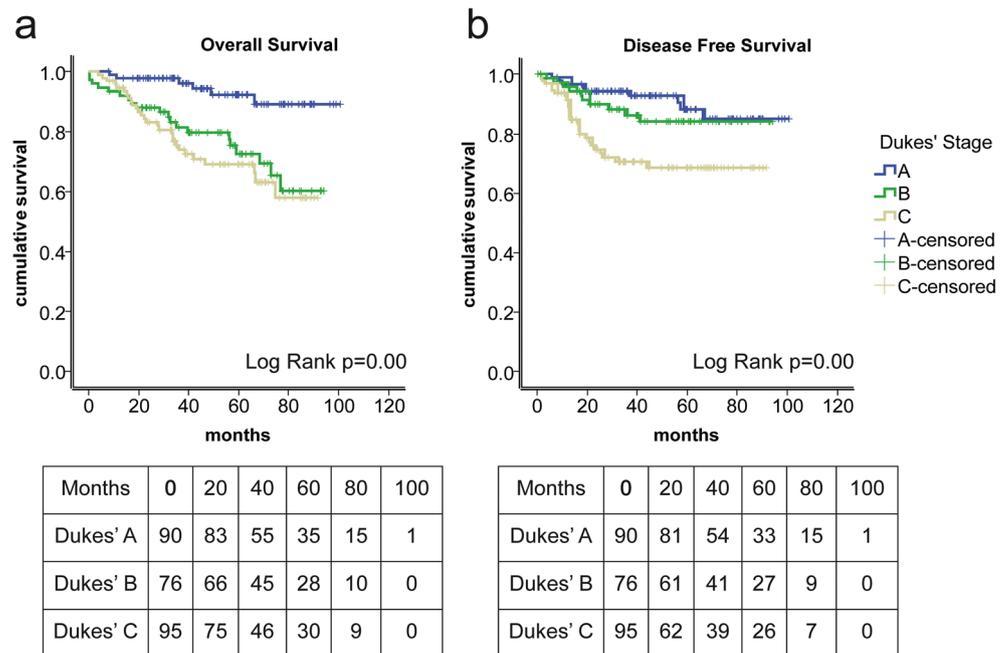
These results have been achieved despite relatively low rates of neo-adjuvant therapy compared with the published

Table 2 Pathological and short-term clinical outcomes

	AP	TQ/AH/NF	P value
Length of stay mean days (S.D)	9.05 (9.31)	8.75 (11.59)	0.79 ^a
Lymph node harvest median (range)	14 (2–48)	16 (2–60)	0.02 ^b
Open conversion % (n)	1.5 (4)	2.6 (3)	0.48 ^c
Operating time in minutes mean (S.D)	229.0 (49.5)	242.9 (45.5)	0.14 ^a
30-day mortality % (n)	0.76 (2)	0	0.44 ^c
Major complications % (n)	19.4 (51)	12.9 (15)	0.14 ^c
R1 resection rate % (n)	3.43 (9)	2.59 (3)	0.47 ^c

^a Independent t test; ^b Pearson correlation; ^c χ^2 test

Fig. 2 Kaplan Meier survival analysis and tables depicting patients ‘at risk’ following TME surgery performed by the principal surgeon including **a** overall survival and **b** disease-free survival according to Dukes’ stage



literature. For example, analyses of large-scale cancer registries in Europe and the USA identify treatment rates with preoperative irradiation between 34.9 and 51.5% respectively [7, 8, 20] compared with 21.2% here.

In the current study, we also examined early post-operative outcome data for three surgeons who had undergone a 12-month period of laparoscopic training under the supervision of the principal surgeon (AP). Although their data is not mature enough to justify scrutiny of long-term outcomes, it is clear that by adopting the same systematic approach to laparoscopic TME surgery, the early post-operative and pathological outcomes including length of stay, lymph node harvest, operating time, 30 day mortality and rate of conversion to open surgery, major complication and R1 resection are comparable with those achieved by the principal surgeon.

We believe that this substantial improvement on contemporary data reflects what can be achieved by standardising laparoscopic technique in one surgeon's hands and then teaching it to trainees willing to submit to similar intra-operative discipline. The greatest single advantage of MIS is that the actual dissection technique can be visualised by anyone with access to a high-definition screen who is willing to watch and listen. Education and training have been identified as key factors for improving the quality of rectal cancer surgery [28], and sub-dividing operations into didactic modules comprising protocolled sequential steps have proven safe and effective training in the laparoscopic era [23].

One potential limitation of our study could be that the limited number of trainees trained by the principle surgeon who have contributed with the data and the wider adaptability and reproducibility of the clinical outcomes.

TME itself started with publications from a single surgeon [3]. Single figure local recurrence rates and all that flowed from them in terms of improved DFS and OS were repeated or improved upon by other individual surgeons, and TME ultimately became a standard unit of cancer surgery practice accepted around the world. We believe that the evaluation of new technologies by analysing results from large numbers of surgeons may impede progress for the technology concerned because some surgeons will initially be less successful than others with any new technique. The large number of rectal perforations, incomplete TME resections and positive CRMs in the non-inferiority trials mentioned bears witness to this. We believe that small groups of disciplined surgeons following a stepwise standard technique demonstrate best what the new technology is capable of. Thus, we hope that this study may point the future more favourably towards MIS, introduce a note of optimism into the prevailing ‘non-inferiority gloom’ and perhaps set new standards for outcome figures for competing techniques such as TaTME and robotic rectal surgery to aspire or improve upon.

Conclusion

The current study demonstrates that laparoscopic TME can produce better oncological and pathological outcomes for patients with rectal cancer than have previously been published. Precision laparoscopic surgery performed in a standardised, stepwise manner has the potential to improve outcomes by setting benchmarks for surgical quality, increasing consistency between centres and promoting a step-by-step TME ‘road-

map' method for surgical training. The early results from those taught by the primary surgeon suggest that standardised stepwise operative routine and improved teaching methods can extend such results into wider surgical practice.

Authors contribution Acquisition of data by Marc Bullock, Anil Hemandas, Tahseen Qureshi, Nuno Figueiredo and Amjad Parvaiz; analysis and interpretation of data was done by Marc Bullock, Irfan Ul Islam Nasir, Anil Hemandas, Tahseen Qureshi, Nuno Figueiredo and Amjad Parvaiz; drafting of manuscript was done by Marc Bullock, Irfan Ul Islam Nasir, Anil Hemandas, Tahseen Qureshi, Nuno Figueiredo, Richard Heald and Amjad Parvaiz; critical revision of manuscript was done by Marc Bullock, Irfan Ul Islam Nasir, Richard Heald and Amjad Parvaiz.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

- MacFarlane JK, Ryall RD, Heald RJ (1993) Mesorectal excision for rectal cancer. *Lancet* 341(8843):457–460
- Heald RJ (1988) The “Holy Plane” of rectal surgery. *J R Soc Med* 81(9):503–508
- Heald RJ, Ryall RD (1986) Recurrence and survival after total mesorectal excision for rectal cancer. *Lancet* 1(8496):1479–1482
- Vennix S, Pelzers L, Bouvy N, Beets GL, Pierie JP, Wiggers T et al (2014) Laparoscopic versus open total mesorectal excision for rectal cancer. *Cochrane Database Syst Rev* 4:CD005200
- Green BL, Marshall HC, Collinson F, Quirke P, Guillou P, Jayne DG, Brown JM (2013) Long-term follow-up of the Medical Research Council CLASICC trial of conventional versus laparoscopically assisted resection in colorectal cancer. *Br J Surg* 100(1):75–82
- Bonjer HJ, Deijen CL, Haglind E, Group CIS (2015) A randomized trial of laparoscopic versus open surgery for rectal Cancer. *N Engl J Med* 373(2):194
- Nussbaum DP, Speicher PJ, Ganapathi AM, Englum BR, Keenan JE, Mantyh CR et al (2015) Laparoscopic versus open low anterior resection for rectal cancer: results from the national cancer data base. *J Gastrointest Surg* 19(1):124–131 discussion 31–2
- Draeger T, Volkel V, Gerken M, Klinkhammer-Schalke M, Furst A (2018) Long-term oncologic outcomes after laparoscopic versus open rectal cancer resection: a high-quality population-based analysis in a Southern German district. *Surg Endosc* 32(10):4096–4104
- Jeong SY, Park JW, Nam BH, Kim S, Kang SB, Lim SB, Choi HS, Kim DW, Chang HJ, Kim DY, Jung KH, Kim TY, Kang GH, Chie EK, Kim SY, Sohn DK, Kim DH, Kim JS, Lee HS, Kim JH, Oh JH (2014) Open versus laparoscopic surgery for mid-rectal or low-rectal cancer after neoadjuvant chemoradiotherapy (COREAN trial): survival outcomes of an open-label, non-inferiority, randomised controlled trial. *Lancet Oncol* 15(7):767–774
- Fleshman J, Branda M, Sargent DJ, Boller AM, George V, Abbas M, Peters WR Jr, Maun D, Chang G, Herline A, Fichera A, Mutch M, Wexner S, Whiteford M, Marks J, Bimbaum E, Margolin D, Larson D, Marcello P, Posner M, Read T, Monson J, Wren SM, Pisters PWT, Nelson H (2015) Effect of laparoscopic-assisted resection vs open resection of stage II or III rectal cancer on pathologic outcomes: the ACOSOG Z6051 randomized clinical trial. *JAMA* 314(13):1346–1355
- Stevenson AR, Solomon MJ, Lumley JW, Hewett P, Clouston AD, GebSKI VJ, Davies L, Wilson K, Hague W, Simes J, ALaCaRT Investigators (2015) Effect of laparoscopic-assisted resection vs open resection on pathological outcomes in rectal cancer: the ALaCaRT randomized clinical trial. *JAMA* 314(13):1356–1363
- Abbas SK, Yelika SB, You K, Mathai J, Essani R, Krivokapic Z et al (2017) Rectal cancer should not be resected laparoscopically: the rationale and the data. *Tech Coloproctol* 21(3):237–240
- Martinez-Perez A, Carra MC, Brunetti F, de’Angelis N (2017) Pathologic outcomes of laparoscopic vs open mesorectal excision for rectal cancer: a systematic review and meta-analysis. *JAMA Surg* 152(4):e165665
- Spinelli A, D’Hoore A, Panis Y, Bemelman WA, Jayne DG, Furst A (2017) Critical appraisal of two randomized clinical trials on pathologic outcomes laparoscopic vs. open resection for rectal cancer. *Coloproctology* 39(4):277
- Quirke P, Durdey P, Dixon MF, Williams NS (1986) Local recurrence of rectal adenocarcinoma due to inadequate surgical resection. Histopathological study of lateral tumour spread and surgical excision. *Lancet* 2(8514):996–999
- Nagtegaal ID, Quirke P (2008) What is the role for the circumferential margin in the modern treatment of rectal cancer? *J Clin Oncol* 26(2):303–312
- Xiong B, Ma L, Huang W, Zhao Q, Cheng Y, Liu J (2015) Robotic versus laparoscopic total mesorectal excision for rectal cancer: a meta-analysis of eight studies. *J Gastrointest Surg* 19(3):516–526
- Penna M, Hompes R, Arnold S, Wynn G, Austin R, Warusavitarne J, Moran B, Hanna GB, Mortensen NJ, Tekkis PP, TaTME Registry Collaborative (2017) Transanal total mesorectal excision: international registry results of the first 720 cases. *Ann Surg* 266(1):111–117
- Guillou PJ, Quirke P, Thorpe H, Walker J, Jayne DG, Smith AM et al (2005) Short-term endpoints of conventional versus laparoscopic-assisted surgery in patients with colorectal cancer (MRC CLASICC trial): multicentre, randomised controlled trial. *Lancet* 365(9472):1718–1726
- Rickle AS, Dietz DW, Chang GJ, Wexner SD, Berho ME, Remzi FH, Greene FL, Fleshman JW, Abbas MA, Peters W, Noyes K, Monson JR, Fleming FJ, Consortium for Optimizing the Treatment of Rectal Cancer (OSTRiCh) (2015) High rate of positive circumferential resection margins following rectal cancer surgery: a call to action. *Ann Surg* 262(6):891–898
- Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD, de Santibañes E, Pekolj J, Slankamenac K, Bassi C, Graf R, Vonlanthen R, Padbury R, Cameron JL, Makuuchi M (2009) The Clavien-Dindo classification of surgical complications: five-year experience. *Ann Surg* 250(2):187–196
- Kehlet H (1997) Multimodal approach to control postoperative pathophysiology and rehabilitation. *Br J Anaesth* 78(5):606–617
- Hemandas A, Flashman KG, Farrow J, O’Leary DP, Parvaiz A (2011) Modular training in laparoscopic colorectal surgery maximizes training opportunities without clinical compromise. *World J Surg* 35(2):409–414
- van der Pas MH, Haglind E, Cuesta MA, Furst A, Lacy AM, Hop WC et al (2013) Laparoscopic versus open surgery for rectal cancer (COLOR II): short-term outcomes of a randomised, phase 3 trial. *Lancet Oncol* 14(3):210–218

25. Jayne DG, Thorpe HC, Copeland J, Quirke P, Brown JM, Guillou PJ (2010) Five-year follow-up of the Medical Research Council CLASICC trial of laparoscopically assisted versus open surgery for colorectal cancer. *Br J Surg* 97(11):1638–1645
26. Galandiuk S (2015) Standardization or centralization: can one have one without the other? Circumferential resection margins and rectal Cancer. *Ann Surg* 262(6):899–900
27. Miskovic D, Foster J, Agha A, Delaney CP, Francis N, Hasegawa H, Karachun A, Kim SH, Law WL, Marks J, Morino M, Panis Y, Uriburu JCP, Wexner SD, Parvaiz A (2015) Standardization of laparoscopic total mesorectal excision for rectal cancer: a structured international expert consensus. *Ann Surg* 261(4):716–722
28. Mack LA, Temple WJ (2005) Education is the key to quality of surgery for rectal cancer. *Eur J Surg Oncol* 31(6):636–644
29. Cheung HY, Ng KH, Leung AL, Chung CC, Yau KK, Li MK (2011) Laparoscopic sphincter-preserving total mesorectal excision: 10-year report. *Color Dis* 13(6):627–631
30. Staudacher C, Di Palo S, Tamburini A, Vignali A, Orsenigo E (2007) Total mesorectal excision (TME) with laparoscopic approach: 226 consecutive cases. *Surg Oncol* 16(Suppl 1):S113–S116
31. Sartori CA, Dal Pozzo A, Franzato B, Balduino M, Sartori A, Baiocchi GL (2011) Laparoscopic total mesorectal excision for rectal cancer: experience of a single center with a series of 174 patients. *Surg Endosc* 25(2):508–514

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.