Surgical Endoscopy (2019) 33:1870–1879
https://doi.org/10.1007/s00464-018-6466-8

Perforation in the peritoneal cavity during transanal endoscopic microsurgery for rectal tumors: a real surgical complication with a challenging prognosis?

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Received: 21 April 2018 / Accepted: 18 September 2018 / Published online: 28 September 2018

Abstract

Background Perforation in the peritoneal cavity during transanal endoscopic microsurgery represents a major challenge. It is usually treated by primary suture, though some authors propose laparoscopic repair with or without ostomy. It is unclear whether perforation increases the risk of tumor dissemination.

Aim The purpose of the study is to assess the safety of primary suture of peritoneal perforation and the long-term risk of dissemination, also, to determine risk factors for perforation and to propose a predictive model for lesions with risk of perforation.

Method This is an observational study with prospective data collection at Parc Taulí University Hospital, Sabadell, of patients undergoing transanal surgery with perforation into the peritoneal cavity from June 2004 to September 2017. The main variable is postoperative morbidity and mortality. The long-term follow-up of local recurrence and peritoneal tumor dissemination is described, and a quantitative predictive model for peritoneal cavity perforation is proposed.

Results Forty-five patients out of 686 (6.6%) presented perforation into the peritoneal cavity. Ten patients (22.2%) in the perforation group had morbidity, a rate similar to the non-perforated group. There was no peritoneal dissemination in patients with adenoma or with carcinoma treated with curative intent. In the quantitative predictive model, risk factors for perforation were proximal edge of tumor > 14 cm from anal verge (6 points), size ≥ 6 cm (2), age ≥ 85 years (4), anterior quadrant (3) , and sex (2). Total scores of ≥ 6 points predicted perforation.

Conclusions Primary suture after peritoneal cavity perforation during transanal surgery is safe and does not increase the risk of recurrence or peritoneal dissemination. Our predictive model provides guidance regarding the risk of perforation and the need to suture the defect after transanal surgery resection.

Keywords Transanal endoscopic microsurgery · Peritoneal perforation · TEM · TEO

Local rectal surgery is an alternative to total mesorectal excision for benign endoscopically unresectable adenomas and for early rectal cancer (T1) [1], obtaining lower morbidity and mortality rates, and presenting a lower risk of genitourinary dysfunction [2, 3].Classic local transanal surgery was unable to reach heights of more than 7–8cm from the anal verge [4].The introduction of transanal endoscopic microsurgery (TEM), first described by Buess [5] in the 1980s, allowed access to lesions up to 20 cm from the anal verge. Subsequently, new devices have been introduced in attempts to simplify the equipment and the technique: TEO [6] (transanal endoscopic operation), which incorporates a high-definition monitor, and TAMIS [7] (transanal minimally invasive surgery) with a single port system, which is compatible with the equipment used in laparoscopic surgery.

With access to higher lesions, the risk of perforation into the peritoneal cavity increases. Therefore, the limits of TEM were initially set by the possibility of perforation. Considered a complication with a risk of abdominal sepsis and tumor dissemination inside the peritoneal cavity, perforation obliged conversion to abdominal surgery [8]. Classically, the

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limits for TEM were 20 cm in posterior lesions and 15 cm in lateral or anterior locations [2]. The reports of the management of peritoneal cavity perforation during the transanal approach [9–15] without any increase in postoperative morbidity suggested that the quadrant involved was no longer a limitation. However, other authors [16, 17] have argued against primary suture and propose that the leak tightness of the perforation should be checked through abdominal surgery by means of a laparoscopic approach, combined, or not with an ostomy.

The possibility of dissemination of benign rectal tumors or early rectal cancers after perforation into the peritoneal cavity is a controversial issue. To date, only a few studies [10, 12, 17] have assessed the possible effect of perforation into the abdominal cavity on the short- or long-term oncological results.

Closure of the defect after the excision is difficult and prolongs TEM surgery. As a result, the possibility of leaving the defect open has been proposed in certain studies [18, 19], and even in one randomized study [20]. If the defect is not closed, however, the patient is exposed to the risk of inadvertent perforation into the peritoneal cavity. To date, the types of lesion that present a risk of perforation into the peritoneal cavity have not been defined.

The main hypothesis of the present study is that the suture of the perforation in the peritoneal cavity after local excision of rectal tumors by TEM/TEO does not increase morbidity or the risk of poor oncological outcome. The systematic closure of the defect avoids the risk of inadvertent perforation.

The main objective of the study is to assess whether the morbidity and mortality rates of patients with perforation into the peritoneal cavity are similar to the overall rates in our TEM/TEO series. We also aim to establish whether patients with perforation present dissemination during long-term follow-up. The secondary objectives were to determine the risk factors for perforation in the abdominal cavity and to propose a predictive model for injuries with risk of perforation in which suture will always be required.

Materials and methods

This is an observational study of patients diagnosed with rectal tumor and undergoing local rectal excision via TEM, at the Coloproctology Unit of the Parc Taulí University Hospital in Sabadell, from January 2004 to September 2017. Data on all our operated patients are recorded prospectively in a computerized database (Microsoft® Access 2003) and introduced in a protected format. Data are recorded anonymously and in accordance with the Spanish data protection act of 1999 (LOPD) [21] and the STROBE guidelines [22] and in this study they are analyzed retrospectively. Patients provided signed informed consent prior to surgery.

All patients who were candidates for TEM underwent preoperative study. Physical examination comprised digital rectal examination and rigid rectoscopy. Complementary tests were total colonoscopy with multifocal biopsy (at least 8), endorectal ultrasound (EUS), and magnetic resonance imaging (MRI) of the pelvis. All the patients were assessed at our weekly multidisciplinary team committee meetings, and were classified into our preoperative surgical indication groups (groups I–V) [23]; group I with curative intent (benign tumors, which after ultrasound (u) and magnetic resonance imaging (MRI) were staged as u-MRI T0-1 and u-MRI N0); group II, with curative intent (low-grade adenocarcinomas, u-MRI T0-1 and u-MRI N0); group III, consensus indication (low-grade adenocarcinomas, u-MRI T2 and u-MRI N0, who reject radical surgery); group IV, palliative indication; and group V, atypical indications [24].

Rigid rectoscopy during endorectal ultrasound allowed visualization of the lesion, its location, and the distance between its upper and lower edges and the anal canal.

Inclusion criteria were patients operated on for a rectal tumor with indication for transanal endoscopic surgery (TEM/TEO) [23], who presented perforation to the abdominal cavity during surgery. Exclusion criteria were patients with atypical therapeutic indications, except those undergoing surgery for neuroendocrine tumors (NET).

All patients scheduled for TEM underwent mechanical preparation of the colon, thromboembolism prophylaxis, and administration of prophylactic antibiotherapy in accordance with our protocol [23]. All patients provided signed informed consent prior to surgery.

Local rectal excision was carried out by transanal endoscopic surgery using TEM (Richard Wolf GMBH, Knittlingen, Germany) or TEO equipment (Karl Storz GmbH, Tüttlingen, Germany) according to availability. All the patients were operated by the five members of the Colorectal Unit. The standard surgical technique was full-thickness wall excision of the lesion in a single piece [23]. The specimen was mounted on a cork base with needles for pathological study. Whenever possible, a complete closure of the defect was made, without tension; otherwise, a partial closure of the most proximal area was performed. Normally, lesions more than five centimeters from the anal margin can be closed completely. Lesions less than five cm from the anal margin can only be closed partially, due to the presence of the sphincters.

In cases of perforation into the abdominal cavity, the perforation was repaired transanally with suture of the full-thickness rectal wall. In cases of large perforations in which the rectum was not distended and the spasms made vision difficult, we waited until the abdominal and rectal pressures were equal. Subsequently, the defect was closed in the manner described above, placing a full-thickness rectal wall stitch in the middle of the defect, followed by two running sutures on either side. The sutures were secured by a silver clip as described previously [23].

At the beginning of the series, patients were discharged on postoperative day 2 or 3. Currently, if there are no complications they are discharged from the hospital on the same day or within 24 h. In case of perforation, patients are admitted for between three and five days, with the introduction of a progressive diet, after 48 h. The same prophylactic antibiotic regimen is continued empirically for 5 days.

Patients with adenomas undergo rectoscopy at 6–12–24 months after surgery and then follow the standard adenoma protocol [23]. Patients with adenocarcinomas are followed up every six months by means of rectoscopy and assessment of tumor markers (CEA and Ca 19.9) during the first 2 years, and then annually for the following 3 years. Complete colonoscopy, abdominal CT, and rectal MRI are performed annually for 5 years [23].

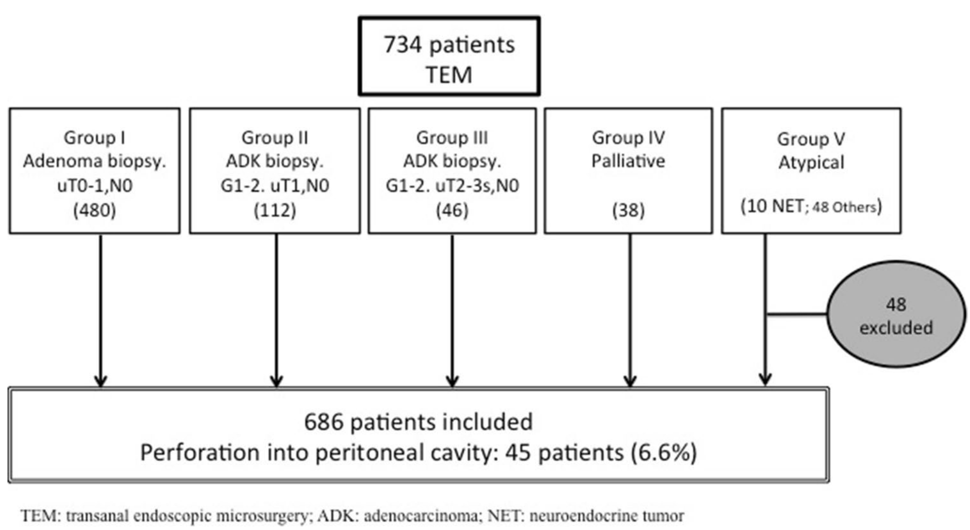
The main variable recorded in the study were global morbidity and mortality according to the Clavien–Dindo classification (CL-D) and clinical morbidity defined as a CL-D grade > I. The secondary variables were preoperative, surgical, postoperative, and follow-up variables. Within the preoperative variables were age (years), sex, ASA classification (American Society of Anesthesiologists), quadrant affected (anterior / posterior / right lateral / left lateral), distance from the anal verge to the upper border (cm), distance from the anal verge to the lower border (cm), and tumor size (cm). Surgical and postoperative variables were surgical time (min), equipment used (TEM/TEO), surgeon's experience (< 35 TEM/TEO, 35–100, 100–150, > 150) [25], anesthesia (spinal / general), suture defect, postoperative stay (days), and pathology of the specimen (adenoma, adenocarcinoma, neuroendocrine, no pathology). Follow-up variables were median follow-up time, presence of local recurrence, presence of peritoneal dissemination, date of last follow-up, and mortality due to neoplasia or other pathology.

For the description of the variables, version 23 of the SPSS program (Statistical Package for the Social Sciences, Inc., Chicago, Illinois) was used. Quantitative variables are described as means with standard deviation and 95% confidence interval when distribution is normal, and otherwise as median, interquartile range (IQR), and range. Categorical variables are described in absolute numbers and percentages. As data were introduced prospectively, there were no missing data. The univariate statistical analysis of the quantitative variables, with independent groups, was carried out using the Student's *T* test, as long as its application conditions were met; otherwise, the Mann–Whitney *U* test was used. For categorical variables, Pearson's X^2 test or Fisher's exact test was used, depending on the conditions. A p value < 0.05 was considered statistically significant, with a 95% confidence interval. Cumulative survival without local recurrence, disease-free, and overall survival were not analyzed due to the low number of patients presenting perforation into the abdominal cavity. A multivariate analysis with a predictive model was performed to identify patients with a higher probability of perforation, using logistic regression. During the construction of the model, the likelihood ratio test was used in all cases. Once the final prediction equation was established, the regression coefficients were converted to scores using test algorithms.

Results

A total of 734 patients underwent TEM during the study period. Figure 1 displays the flowchart of these patients according to group of surgical indication (group I–V). Ten of the 58 patients in the atypical group were NET, and so a total of 48 patients were excluded. In all, 686 patients were included in the study, of whom 45 (6.6%) presented perforation into the abdominal cavity. There were no statistically

Fig. 1 Flowchart of patients



significant differences between perforation and non-perforation groups in terms of the clinical tumor classification. All these 45 patients with perforation were repaired transanally, except one who was converted to open surgery due to the impossibility of reconstruction (Clavien–Dindo complication grade IIIb). Checking of the suture by laparoscopy and/or diverted ileostomy was not required in any of the patients.

Tables 1, 2, and 3 show the overall series and compare the demographic, tumor-related, and operative and postoperative variables of patients with and without perforation to the abdominal cavity. Morbidity or mortality in the first 30 days post-surgery was recorded in ten patients with perforation into the abdominal cavity (22.2%); the rates did not differ significantly from the group without perforation (145, 22.6%). Nor were there differences in septic events between the two groups. Of these ten patients, six presented rectal bleeding: four self-limited (grade I), one that required control by colonoscopy (grade IIIa), and the other that required reoperation by transanal surgery (grade IIIb). One patient presented an infected hematoma (grade II); another was converted to open surgery due to the impossibility of reconstruction (grade IIIb), and another with ischemic heart disease presented an acute pulmonary edema that required admission to the intensive care unit (grade IV). The last patient, with cirrhosis of the liver, presented right colon bleeding and hepatic decompensation, and died three weeks after TEM (grade V). Six patients (13.6%) presented clinical morbidity (Clavien–Dindo > I). The Comprehensive Complication Index (CCI), which reflects the importance of the complications of a procedure, presented a median score of 0 (IQR 0).

During a mean follow-up period of 48 months (SD ± 38) (range 1–130), four patients (8.9%) presented local recurrence and two (4.5%) peritoneal disseminations, all of them with free margins in the definitive pathology study. Two patients with local and peritoneal dissemination, in the palliative indication group (adenocarcinoma), were found to be a pT2 and a pT3 in the definitive pathology and died after 35 and 22 months, respectively. Two instances of local recurrence were recorded in the same patient who underwent surgery twice, and presented perforation into the abdominal cavity both the times: the first due to an adenoma, with free margins, and the second due to a recurrence of the adenoma at 16 months, with a definitive pathology study of pT2; the patient was rescued to radical surgery and presented a new recurrence, and died after 34 months. The other patient with local recurrence was a pT1 in the definitive pathology study, which presented with multiple bilobar hepatic metastases in the recurrence. The patient was assigned to palliative treatment and died 18 months after transanal surgery.

Table 1 Demographic variables of the global series, of patients with and without abdominal cavity perforation

	Global ($n=686$)	No perforation ($n=641$)	Perforation ($n=45$)	*p*
Median age (IQR) (min–max) years	71 (17) (31–92)	71 (17) (31–92)	74 (16) (40–92)	0.033*[a]
Age (%)				
< 75 years	420 (61.2%)	396 (94.3%)	24 (5.7%)	0.028*[b]
75–84 years	223 (32.5%)	209 (93.7%)	14 (6.3%)	
≥ 85 years	43 (6.3%)	36 (83.7%)	7 (16.3%)	
Sex (%)				
Men	413 (60.2%)	389 (94.2%)	24 (5.8%)	0.206[c]
Women	273 (39.8%)	252 (92.3%)	21 (7.7%)	
ASA Risk (%)				
I	23 (3.4%)	23 (100%)	0	
II	360 (52.5%)	334 (92.8%)	26 (7.2%)	0.573[b]
III	247 (36%)	232 (93.9%)	15 (6.1%)	
IV	56 (8.2%)	52 (92.9%)	4 (7.1%)	
PP years (%)				
2004–2007	144 (21%)	135 (93.8%)	9 (6.2%)	
2008–2010	185 (27%)	168 (91.8%)	17 (9.2%)	0.391[b]
2011–2013	152 (22.1%)	144 (94.7%)	8 (5.3%)	
2014–2017	205(29.9%)	194 (94.6%)	11 (5.4%)	

IQR interquartile range; *ASA* American Society of Anesthesiologists classification; *PP Years %* perforation per group of years

[a]Mann–Whitney *U* test

[b]Pearson's chi-squared test

[c]Fisher test

Table 2 Variables related to the tumor comparing the groups of the global series, of patients with and without abdominal cavity perforation

	Global ($n=686$)	No perforation ($n=641$)	Perforation ($n=45$)	p
Median tumor size (IQR) (min–max) cm	4 (2) (0–12)	4 (2) (0–11)	4 (4) (1–12)	0.005*[a]
Tumor size (%)				
< 3 cm	121 (17.6%)	115 (95%)	6 (5%)	
3–6 cm	455 (66.3%)	434 (95.4%)	21 (4.6%)	< 0.001*[b]
6 cm	110 (16%)	92 (83.6%)	18 (16.4%)	
Quadrants (%)				
Anterior	179 (26.1%)	159 (88.8%)	20 (11.2%)	
Right lateral	172 (25.1%)	159 (92.4%)	13 (7.6%)	0.004*[b]
Left lateral	137 (20%)	129 (94.2%)	8 (5.8%)	
Posterior	198 (28.9%)	194 (98%)	4 (2%)	
Median anal verge distance (IQR) (min–max) cm	7 (5) (2–22)	7 (5) (2–22)	10 (6) (2–19)	< 0.001*[a]
Median upper lesion margin (IQR) (min–max) cm	11 (4.6) (2–26)	10.5 (5) (2–26)	16 (7) (6–22)	< 0.001*[a]
Upper margin (%)				
< 6 cm	40 (44.9%)	40 (100%)	0	
6–10.9 cm	288 (42%)	282 (97.9%)	6 (2.1%)	< 0.001*[b]
11–14.9 cm	232 (33.8%)	220 (94.8%)	12 (5.2%)	
≥ 15 cm	126 (18.4%)	99 (15.4%)	27 (21.4%)	
Lower margin (%)				
< 6 cm	250 (36.4%)	248 (99.2%)	2 (0.8%)	
6–10.9 cm	341 (49.7%)	315 (92.4%)	26 (7.6%)	< 0.001*[b]
11–14.9 cm	66 (9.6%)	56 (84.8%)	10 (15.2%)	
≥ 15 cm	29 (4.2%)	22 (78.6%)	7 (21.4%)	

IQR interquartile range

[a]Mann–Whitney *U* test

[b]Pearson's chi-squared test

During this follow-up period, 12 patients (27.3%) were exitus after a mean of 41 months (SD ± 38) (range 6–122): four due to rectal cancer (already discussed above) and eight due to other causes (medical or other neoplasms).

In the logistic regression analysis, all the variables with statistical significance and those close to it were included ($p < 0.2$). The final predictive model of peritoneal cavity perforation was obtained by applying the criteria outlined in the materials and methods section. The variables obtained were proximal edge of the tumor > 14 cm, tumor ≥ 6 cm, age ≥ 85 years, anterior quadrant, and sex. Sex was entered into the equation in order to adjust the model, not because of its significance (Table 4). This procedure, with a cut-off point of 0.16, obtained a sensitivity of 92.6%, a specificity of 90.9%, a PPV of 30.1%, and an NPV of 99.66%. Once the test algorithms were calculated based on the coefficients obtained, the scores were assigned to each variable. If the sum of all the scores reached six points or more, the risk of perforation can be predicted with the PPV and NPV just mentioned. Figure 2 shows the precision ROC curve of the model obtained, which achieves an area under the curve of 81.3%, with 95% confidence intervals between 74.2 and 88.4%.

Discussion

The rate of perforation in our study was 6.6%, a value within the range published in the literature (2.5–32%). Table 5 displays a series of studies that have paid special attention to abdominal cavity perforation during TEM. Our series is the largest described to date at a single center.

Although the difference was not statistically significant, in our series we found an increase in perforations in the first six years, with a subsequent stabilization and then a slight rise in the last four years. A similar trend has also been described by other authors in recent years [12, 14], and probably reflects the high level of care taken with the initial cases and the rise in the indications for higher and larger lesions as more experience is accumulated.

Although no statistically significant differences were observed with regard to sex, the fact that women have a lower anterior peritoneal reflection than men increases the frequency of perforations, and so sex was identified as a predictive factor by multivariate analysis. Perforations are associated with longer surgical time, due to the need for closure and also probably due to the difficulty of the resection given the distance from the anal verge and the tumor size [9,

Table 3 Operative and postoperative variables of the overall series, of patients with and without abdominal cavity perforation

	Global ($n=686$)	No perforation ($n=641$)	Perforation ($n=45$)	p
Median surgical time (IQR) (min–max) (min)	70 (50) (35–265)	70 (50) (35–265)	105 (76) (35–240)	<0.001*[a]
Type resection (%)				
Full-thickness	678 (98.8%)	633 (93.4%)	45 (6.6%)	0.726[b]
Partial	(1.2%)	8 (100%)	0	
Surgeon experience (%)				
< 50 surgeries	69 (10.1%)	67 (97.1%)	2 (2.9%)	0.262[b]
50–100 surgeries	160 (23.3%)	147 (91.9%)	13 (8.1%)	
100–150 surgeries	133 (19.4%)	121 (91%)	12 (9%)	
> 150 surgeries	324 (47.2%)	306 (94.4%)	18 (5.6%)	
Surgical tools (%)				
TEM	349 (50.9%)	323 (92.6%)	26 (7.4%)	0.616[b]
TEO	337 (49.1%)	318 (94.3%)	19 (5.7%)	
Type anesthesia (%)				
General	622 (90.7%)	581 (93.5%)	41 (6.5%)	0.327[b]
Locoregional	64 (9.3%)	60 (93.8%)	4 (6.2%)	
Histology (%)				
Adenoma	400 (58.3%)	374 (93.5%)	26 (6.5%)	
Adenocarcinoma	221 (32.2%)	208 (94.1%)	13 (5.9%)	0.498[b]
Neuroendocrine	9 (1.3%)	9 (100%)	0	
No pathology	56 (8.2%)	50 (89.3%)	6 (10.7%)	
Median postoperative stay (IQR) (min–max) (days)	3 (2) (0–34)	3 (2) (0–34)	4 (3) (2–26)	<0.001*[a]
30-d morbidity (%)	155 (22.6%)	145 (22.6%)	10 (22.2%)	0.560[a]
30-d clinical morbidity (%)	59 (8.6%)	53 (8.3%)	6 (13.6%)	0.181[a]
Median CCI (IQR) (min–max)	0 (0)	0 (0)	0 (0)	0.823[b]

D day; *CCI* Comprehensive Complication Index

[a]Mann–Whitney *U* test

[b]Pearson's chi-squared test

Table 4 Multivariate analysis of risk factors for abdominal cavity perforation

Risk factor	p	OR (ExpB)	95% CI	Score (points)
Upper margin > 14 cm	0.000	9.250	4.594–18.625	6
Tumor size ≥ 6 cm	0.008	2.619	1.285–5.339	2
Age ≥ 85 years old	0.005	4.283	1.533–11.966	4
Anterior quadrant	0.001	3.079	1.547–6.129	3
Sex (Female)	0.020	0.440	0.221–0.877	2

p significance. *OR* Odds ratio. *95% CI* 95% confidence interval

12, 14, 15]. As Table 2 shows, although lesions located in the anterior quadrant had a perforation rate of 11.2%, rates on the right and left sides were also high, at 7.6% and 5.8%, respectively. Even though the lateral location did not emerge as a predictive factor of perforation, these figures were at least three times higher than those recorded in the posterior quadrant.

Transanal closure of the perforation defect is safe, and does not require the creation of a protective stoma [9–15]. Although some authors advocate systematic laparoscopy to check the closure of the defect [16, 17], transanal closure was performed by means of a continuous suture during surgery in all but one of our patients. Well-vascularized edges, the absence of tension in the suture due to the mobility of the sigma, and the technical expertise of a trained surgeon all serve to avoid suture dehiscence after perforation. In only one case (at the beginning of the series, when our group was still relatively inexperienced) was conversion to abdominal surgery necessary; in that case, reconstruction was impossible because the proximal end could not be recovered by transanal surgery.

Policy on empirical antibiotic treatment after perforation into the abdominal cavity is controversial. Some authors [15] recommend maintaining antibiotics post-surgery, but others [9] do not. We maintain empirical antibiotic treatment on the grounds that the peritoneal cavity has been contaminated.

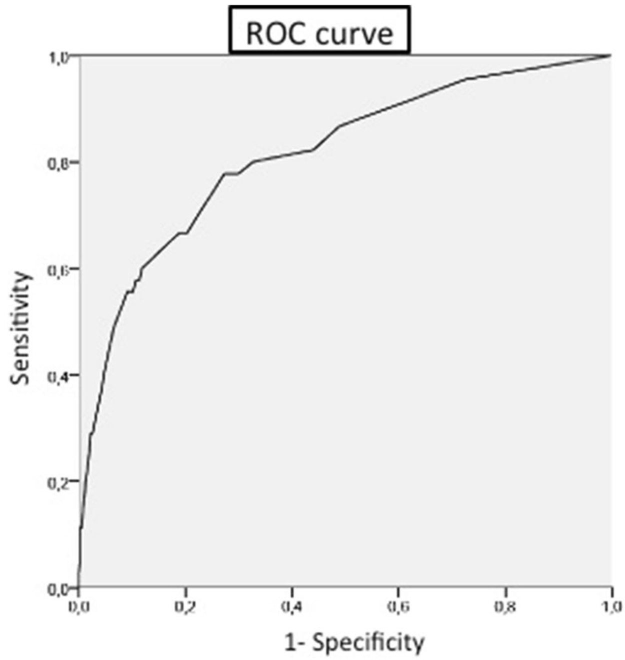


Fig. 2 ROC accuracy curve of the predictive model described. Area under the curve 81.3%

Overall morbidity and clinical morbidity (Clavien–Dindo > I) rates of patients with perforation were 22.2% and 13.6%, respectively, which are within the range of previously published reports (Table 5). We did not find statistically significant differences between patients with and without perforation in the abdominal cavity. Only one patient died in the first 30 postoperative days, and the death was unrelated to the surgical technique. Hospital stay was significantly longer in patients with perforation, who underwent more conservative postoperative management [12].

Few studies in the literature report the long-term oncological results due to peritoneal dissemination after perforation into the peritoneal cavity. Although the number of patients with perforation into the abdominal cavity is low, in our study and in previous series the perforation does not seem to be related to an increase in local or distant recurrence. Percentages of local recurrence of 3.6–9.9% have been described [10, 12, 14, 15, 17] with a mean follow-up of 12–48 months. Recurrences are mostly recorded in patients with palliative pT2 or pT3 or who refuse rescue surgery. However, Baatrup et al. [10] reported a case of a patient with low risk pT1, Marks et al. [15] a patient with a pT2 who had received neoadjuvant treatment, and Mege et al. [17] a patient with adenoma. In our study, four patients (8.9%) with adenocarcinomas presented local recurrence, a figure within the range described in the literature. As for distant recurrence, our series includes two peritoneal recurrences (4.5%), both in patients with palliative indication. In the literature, rates of distant recurrence range from 3.6 to 13.6%, with an average follow-up of 12–48 months [10, 12, 17]. Only four of the 12 patients who died during follow-up died from the disease. Two of these patients had been treated with palliative intent: one patient with a pT2 that required rescue surgery and presented subsequent unresectable local recurrence, and the other with a pT1 who presented a new recurrence with unresectable liver metastases.

Recently, studies have proposed leaving the resection defect open if perforation is not detected, given that no differences have been demonstrated in terms of bleeding and infection [18, 19] although the closure of the defect is associated with a lower percentage of readmissions [19]. However, we believe that systematic closure of the defect not only develops the surgeon's ability to close a possible peritoneal cavity perforation when necessary, but also avoids the risk of inadvertent perforation and the resulting fecaloid peritonitis, regardless of the height and location of the lesion. Given the current lack of definition regarding the risk of perforation in the peritoneal cavity during TEM, we aimed to identify these risk factors and to create a predictive model.

The univariate and multivariate analyses identified risk factors for perforation. Some of them have already been reported elsewhere, such as distance from the anal verge [12, 14, 15, 17, 26], location in the anterior quadrant [12, 14, 17, 26], and tumor size [12, 14, 15]. In our study, we considered the distance from the upper edge of the lesion to the anal verge as the main risk factor. We think that this distance is one of the key factors determining the limits of the technique. A variety of cut-off points have been proposed for the distance from the anal verge: >7 cm [12], > 10 cm [14, 17, 25], and > 12 cm [15]. In our study we established a limit of 14 cm. Even so, the presence of a high lesion is not always associated with perforation, since in certain patients an area of fatty tissue separates the rectal wall from the peritoneal layer and thus keeps them apart. Another factor was age older than 85 years, since with advanced age the floor of the pelvis decreases and the risk of perforation into the peritoneal cavity rises.

Other risk factors have been described in the literature, such as circumferential lesions [12, 17] and diagnosis of cancer [14]. Cancer diagnosis was not significant in our series. Molina et al. [15] reported an association between the use of TAMIS and rigid platforms, considering that in high and/or near-circumferential lesions, the use of TAMIS is inappropriate. These authors report the need for conversion to TEM/TEO15 for the correct closure of the transanal defect. In our series, there were no statistically significant differences when using TEM or TEO equipment.

The predictive model proposed in our study indicates a risk of perforation in female patients aged 85 years or older, with lesions ≥ 6 cm and with a border > 14 cm from the anal verge, with a sensitivity of 92.6% and a specificity

Table 5 Literature review of perforation to the abdominal cavity during transanal endoscopic surgery

Author (year)	Equipment	Patients (*n*)	% PP	Repair PP	No. stoma	Lap check	Morbidity *n* (%)	LR *n* (%)	DR *n* (%)	Median FU
Gavagan (2004) [9]	VTEM	34	11 (32.4%)	Transanal	No	No	Minor: 5 (45.5%) Major: 0	NA	NA	–
Ramwell (2009) [11]	TEM	257	15 (5.8%)	Transanal	6	If doubts	4 (26.7%)	NA	NA	-
Baatrup (2009) [10] Retrospective multicenter	TEM	888	22 (2.5%)	Transanal	No	No	1 (4.5%)	2 (9.9%) 1pT1/14 1pT2/4	3(13.6%)	37 m
Morino (2013) [12]	TEM/TEO	481	28 (5.8%)	25 Transanal 3 LAR	No	No	1(3.6%)	2 (7.1%) 1pT2 1pT3	2 (7.1%) 1pT2 1pT3	48 m
Eyvazzadeh (2014) [13]	TEM	445	28 (6.3%)	Transanal	No	No	Minor 6 (21.4%) Major: 2 (7%)	NA	NA	
Marks (2014) [14]	TEM	303	26 (8.6%)	23 Transanal	3	No	5 (19.2%)	1(3.8%) pT2	0	21 m
Molina (2016) [15]	TEM/TEO/TAMIS	78	22/(28.2%)	20 Transanal 1 LAR 1 Hartmann	No	No	1 (4.5%)	1 (4.5%) pT2	0	21 m
Issa (2016) [16]	TEM	141	19 (13%)	Transanal	No	12	2 (10.5%)	NA	NA	-
Mege (2017) [17]	TEO	194	28 (14.4%)	6 Transanal 20 abdominal 2 LAR	4	24	9 (32%)	1 (3.6%) adenoma	1 (3.6%) pT3	
Present study	TEM/TEO	686	45 (6.6%)	44 Transanal 1HAR	No	No	Global 10 (22.2%) Clinical 6 (13.6%)	4 (8.9%)	2(4.5%)	48

PP peritoneal perforation; *Lap* laparoscopic check; *LR* local recurrence; *DR* distant recurrence; *FU* follow-up; *m* months; *VTEM* videoendoscopic transanal tumor resection; *NA* not available; *LAR* low anterior resection. *HAR* high anterior resection of 90.9%. The positive predictive value was 30.1% due to the low prevalence of perforation in our series. No predictive models of the need to suture the defect after resection of the lesion have been described to date. We propose that with a score of ≥ 6, the risk of perforation in the abdominal cavity is high; though, we always recommend closure of the defect, in these cases suture is mandatory.

The main limitation of the study is its observational and single-center design, which means that the results may not be generalizable to other settings. Another limitation is the absence of predictive pathological parameters such as angiolymphatic invasion or T-stage. This may raise the likelihood of false negative results, since the non-perforation group might present other risk factors that can also lead to local recurrences.

Obviously it is difficult to draw firm conclusions with data from 45 patients, although this is one of the largest series published to date. Among the study's strengths, the prospective data collection during the last 14 years means that there are no missing data and patients were followed up continuously. Since the beginning, our group has used the same technique and has applied the policy of primary suture in cases of perforation. We conclude that primary suture after perforation into the peritoneal cavity in transanal endoscopic surgery is safe, and does not entail more morbidity and mortality than a conventional TEM procedure. Nor is there a greater risk of recurrence or peritoneal dissemination. We favor closing the defect in all cases; however, surgeons who usually leave the defect open may benefit from applying our predictive model, because it identifies cases in which suture of the defect is mandatory and thus avoids the risk of inadvertent perforation.

Acknowledgements We thank the rest of the members of the Coloproctology Unit for applying the study protocol. We thank Cristina Gomez Vigo for correcting the manuscript and Michael Maudsley for helping with English.

Author contribution All named authors have made the following contributions to the manuscript: (1) substantial contributions to conception and design, and/or acquisition of data, and/or analysis and interpretation of data; (2) participation in drafting the article or revising it critically for important intellectual content; and (3) approval of the final version to be submitted and any revised version.

Funding No financial support was provided for the study.

Compliance with ethical standards

Conflict of interest Xavier Serra-Aracil, Anna Pallisera-Lloveras, Laura Mora-Lopez, Pere Rebasa, Sheila Serra-Pla, and Salvador Navarro have no conflicts of interest or financial ties to disclose.

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