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Effect of transanal total mesorectal excision for rectal cancer: comparison of short-term outcomes with laparoscopic and open surgeries

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Abstract

Objective To compare short-term results of total mesorectal excision (TME) for mid and low rectal cancer, achieved by transanal (TaTME), laparoscopic (LaTME), and open (OpTME) approaches.

Background The impact of TaTME on the surgical treatment of mid and low rectal cancer has yet to be clarified.

Methods This is a case-matched study, based on data from a prospectively maintained database of patients who underwent TaTME from May 2015 to March 2017, and a retrospective chart review of patients who underwent LaTME and OpTME in the previous period. Each patient in the TaTME group was matched to one LaTME and one OpTME based on sex, BMI, tumor status, and the height of the tumor from the anal verge. Primary end-points were rates of positive circumferential resection margin (CRM), distal resection margin, and the macroscopic quality of the surgical specimen. Composite of these outcomes was compared as an indication for successful surgery. Secondary end-points included intraoperative data and postoperative course and complications.

Results Three hundred patients were included (TaTME = 100, LaTME = 100, OpTME = 100). The three groups were comparable in the baseline characteristics. TaTME resulted in lower rates of incomplete TME specimens than LaTME, but not OpTME ($P = 0.016$, $P = 0.750$, respectively). The rates of CRM involvement, mean CRM distance, and the percentages of successful surgery were comparable among the three groups ($P = 0.368$). The conversion to open surgery occurred only in the LaTME group. TaTME resulted in shorter operation time and less blood loss than the other two groups ($P < 0.001$ and $P < 0.001$). Hospital stay was shorter in the TaTME group ($P = 0.002$); complication rate and mortality were comparable among the groups.

Conclusions TaTME had, in our hands, some obvious benefits over other approaches. The pathological results were not significantly superior to LaTME and OpTME. The procedure is however feasible and safe. Further studies are needed to evaluate the long-term oncological and quality of life outcomes.

Keywords Rectal cancer surgery · Total mesorectal excision · Laparoscopy · TaTME

While total mesorectal excision (TME) has improved the outcomes of rectal cancer surgery [1–3], the impact of minimally invasive surgery on treatment outcomes and the choice of the optimal approach to treat this common form of cancer needs to be clarified. Contradicting results have been found in different controlled randomized studies, comparing the outcomes after open vs. laparoscopic surgery [4–7]. While LaTME has apparent advantages in the form of shorter recovery, its impact on the pathological results is debatable. The main challenges facing LaTME are related to the dissection and bowel transection in the deeper part of the pelvis. Conversion rates during LaTME are still significantly high [4]. Even more concerning are the high rates of involved radial margins of the removed mesorectal specimens [8, 9], rendering rectal cancer surgery one of the most challenging procedures in colorectal surgery. The emergence of TaTME as an evolution to the standard laparoscopic approach could probably solve some of the technical challenges of LaTME

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[10–12]. We aimed through this study to compare our own results after TaTME with those after LaTME and OpTME in the previous years. All three surgical procedures were routinely performed for all incomers with mid and low rectal cancer during the specific periods. To our knowledge, well-implemented rectal cancer surgery procedures at a large-volume colorectal center reflect the standard state of care in most colorectal units around the world.

Methods

We have implemented the TaTME procedure in our unit since 2013 and have published our early short-term results of the first 25 cases [13]. A prospective database is maintained to continuously audit results of all performed TaTME surgeries at Slagelse Hospital. The database has been approved by the Danish Data Protection Agency. The project was approved as a quality insurance project by the institutional board. Informed consent was obtained from all patients prior to surgery and data collection. For the purpose of this present analysis, we have chosen to include consecutive patients who underwent TaTME following our initial 25 cases. These initial cases were not included as these were during learning curve for TaTME, and to avoid repeat publication of the same cohort. Thus, we have included the further 100 cases of TaTME procedures who were operated from May 2015 to March 2017. These 100 patients were matched to patients who underwent LaTME and OpTME in the previous years, excluding patients who underwent LaTME already described in our previous publication [13]. Data from these patients were prospectively registered as part of the clinical quality surveillance, in the database of the Danish Colorectal Cancer Group (DCCG). Data collection to this national clinical database includes baseline demographic data, preoperative data, and limited information about the surgical procedures and the postoperative course [14]. Patients were included when TME was the operative principle, regardless of whether sphincter-saving procedure or resection and colostomy were planned. Exclusion criteria included extralevator abdominoperineal excision and standard abdominoperineal excision. Only patients with tumors 4–11 cm from the anal verge were included. Patients with T4 tumors were included if radical surgery was found to be achievable following preoperative neoadjuvant chemoradiation.

Thus, we matched 100 patients who underwent TaTME to 200 patients who underwent LaTME and OpTME, from a cohort of 384 patients (LaTME = 100, OpTME = 100). We have first analyzed the baseline characteristics between the whole cohort and patients who underwent TaTME, and found no significant difference. We then performed case matching using propensity score matching [15] based on the following criteria: sex, BMI, tumor status, and height of the tumor from the anal verge. Each patient in the TaTME group was matched to one patient who underwent LaTME and one who underwent OpTME (matching: TaTME: LaTME = 1:1, TaTME: OpTME = 1:1). The following data were collected from patient charts: operative data, postoperative course, and pathological data.

Our method of preoperative diagnostic work-up and details of the surgical steps for TaTME and LaTME procedures, as well as details about the postoperative care regime, are described in detail in our previous publication [13]. OpTME procedure is also well described in the literature [1–3]. Patients were offered the standard surgical care of the particular study period (open, laparoscopic, or transanal). Patients were offered TME surgery for tumors at or below 10 cm from the anal verge, and occasionally for tumors located higher up (11–12 cm from the anal verge). Patients with advanced T3 tumors (distance of < 5 mm from the deepest tumor invasion in the mesorectum to the mesorectal fascia and located 5–10 cm from the anal verge as well as all T3 tumors below 5 cm from the anal verge) and those with T4 tumors were treated with preoperative long-course neoadjuvant chemoradiation. The radiation dosage was 50.4 Gy, 28 fractions in combination with 5-fluorouracil or equivalent chemotherapy, according to the DCCG guidelines [16]. At approximately 6 weeks following the end of chemoradiation, new CT and MRI scans were obtained to reassess the tumor and to exclude metastatic disease. Surgery was performed 8–12 weeks after the completion of chemoradiation. Patients planned for sphincter-saving procedure received oral mechanical bowel preparation with Moviprep (Norgine Danmark A/S Stamholmen, 2650 Hvidovre, Denmark); otherwise, they received only enema preparation.

Histopathological examination of the specimens followed a standardized method as described by Quirke et al. [17, 18]. The quality of the removed TME specimen was graded as complete, nearly complete, or incomplete. The CRM, DRM, lymph node yield, and involvement were reported systematically. An involved CRM or DRM was defined as the distance of < 1 mm from the tumor to the inked surface of the fixed specimen or from the tumor to the distal cut edge of the tissue, respectively.

Primary end-points were the rates of involved CRM and DRM, as well as the quality of the removed TME specimen. In addition, we have calculated the surgical success based on a composite of the above outcomes as reported in the recent ACOSOG Z6051 randomized clinical trial [5]. Accordingly, we considered the TME surgery as successful when all of the following criteria were fulfilled: (1) clear CRM (defined as a distance ≥ 1 mm between the deepest extent of tumor invasion into the mesorectum and the inked surface on the fixed specimen); (2) clear DRM (defined as the distance ≥ 1 mm between the tumors to the distal cut edge of the tissue); and (3) a TME specimen quality graded as complete (the entire specimen is smooth with no defects) or nearly complete (minor defects accepted up to 5 mm, and minor conning accepted) as suggested by Quirke et al. [18].

Secondary end-points included intraoperative outcomes and postoperative course and complications. Operation time was defined as the time from the skin incision/insertion of the first laparoscopic port to the last stich for skin closure or stoma creation. For TaTME, this included the time spent to prepare for the transanal part of the procedure. Conversion was defined as any skin incision used to perform dissection in the LaTME or TaTME group, other than a Pfannenstiel incision to perform specimen extraction. Bowel perforation was defined as the perforation of the rectum during the dissection. The decision to plan for sphincter-saving surgery was always taken at the outpatient clinic, based on tumor height, sphincter function, and patient wish. Whether or not the planned anastomosis could be performed during the operation depended on the technical difficulties and intraoperative complications, for example major bleeding.

The postoperative complications were defined as any adverse event within 30 days after surgery. Complications were graded according to the classification system described by Dindo et al. [19]. Anastomotic leakage was defined as clinically suspected and radiologically proven, and in which active therapeutic intervention was performed. Urinary dysfunction was defined as the inability of spontaneous voiding at discharge. Stoma complication was defined as any complication related directly to the stoma itself (ileostomy or colostomy). Hospital stay was calculated from the day of the surgery to discharge. Enhanced recovery program was not the standard of postoperative care for patients in this study. Discharge from the hospital was considered when patients did not show signs of complications, tolerated oral diet, and when capable of independent stoma care or home-nurse help could be arranged.

Statistical analysis

The statistical analyses were performed using the software package SPSS version 24.0 (SPSS 24.0; SPSS Inc., Chicago, Illinois, USA). Data are presented as mean with standard deviation. Categorical variables were compared by Pearson's χ^2 test or Fisher's exact test when appropriate. Continuous variables were compared by Student's t test. Quantitative differences between the three groups were analyzed using one-way analysis of variance to perform multiple comparisons. Probability adjustments were performed by Bonferroni correction and two-sided Dunnett's test for the post hoc between-group comparisons, comparing each of the LaTME and OpTME groups to the TaTME group separately. A P value < 0.05 was considered statistically significant.

Results

Baseline characteristics

The baseline patient and tumor characteristics are summarized in Table 1. No statistically significant differences were found among the three groups, regarding these characteristics. A larger number of patients in the LaTME group have received preoperative neoadjuvant chemoradiation, although the difference did not reach statistical significance. Tumor site ratio was comparable among the groups ($P = 0.490$), as well as tumor (T) and metastasis (M) status ($P = 0.096$ and $P = 0.719$, respectively). Lymph node (N) status was significantly different among the groups ($P < 0.001$). However, N status had no influence on the choice of the operative strategy or the choice of preoperative neoadjuvant chemoradiation according to our guidelines. A comparable number of patients have had a previous abdominal operation ($P = 0.422$).

Pathological results

Pathological results are summarized in Table 2. Quality of the TME specimen in all 300 patients in this study was complete (64.7%) and nearly complete (18.3%) in 83% of cases. Multiple comparisons revealed a statistically significant difference among the groups ($P = 0.041$). Paired group comparisons showed that the difference was significant only between the TaTME and LaTME groups. The TaTME group had the lowest rates of incomplete specimens (TaTME vs. LaTME, $P = 0.016$; TaTME vs. OpTME, $P = 0.082$; LaTME vs. OpTME, $P = 0.750$). A larger number of patients in the LaTME group had involved CRM margins than the other two groups and the rates were the lowest in the TaTME group. However, differences did not reach statistical significance ($P = 0.368$). Paired group comparisons were not significantly different either (TaTME vs. LaTME, $P = 0.157$; TaTME vs. OpTME, $P = 0.447$; LaTME vs. OpTME, $P = 0.560$). The mean CRM distance was also comparable among the groups ($P = 0.849$), likewise after paired comparisons (TaTME vs. LaTME, $P = 0.906$; TaTME vs. OpTME, $P = 0.849$; LaTME vs. OpTME, $P = 0.992$). The DRM was involved in two patients (OpTME = 1; LaTME = 1). The mean DRM distance was longer in the OpTME group compared to the other two groups, although the difference did not reach statistical significance ($P = 0.052$). Paired comparisons showed comparable results as well (TaTME vs. LaTME, $P = 0.995$; TaTME vs. OpTME, $P = 0.065$; LaTME vs. OpTME, $P = 0.052$). Subgroup analysis of patients undergoing sphincter-saving surgery showed a significantly longer DRM distance in the OpTME group compared to the other two groups (TaTME vs. LaTME, $P = 0.826$; TaTME vs. OpTME, $P < 0.001$; LaTME vs. OpTME, $P = 0.002$).

Table 1 Patient and tumor characteristics

	TaTME (100)	LaTME (100)	OpTME (100)	*P* value
Sex				0.864
Female	28	31	28	
Male	72	69	72	
Age, mean ± SD, year	67.33 ± 10.807	66.86 ± 10.733	68.19 ± 8.910	0.646
BMI, mean ± SD, kg/m^2	25.65 ± 3.924	25.43 ± 4.437	26.75 ± 4.833	0.074
ASA classification				0.086
ASA 1	41	36	29	
ASA 2	39	53	49	
ASA 3	20	11	22	
WHO performance status				0.879
0	71	68	74	
1	23	24	21	
2	6	8	5	
Previous abdominal surgery, no.	23	23	30	0.422
Tumor height, mean ± SD, cm	7.53 ± 1.972	7.83 ± 1.781	7,92 ± 1.779	0.296
Tumor height, cm				0.564
≤ 6 cm	35	28	31	
> 6 cm	65	72	69	
Tumor site				0.490
Circumferential	40	47	52	
Anterior	18	12	13	
Posterior	14	19	11	
Right	16	14	11	
Left	12	8	13	
TNM classification				0.096
T				
T2	56	45	37	
T3	43	53	62	
T4	1	2	1	
N				< 0.001
N0	81	34	27	
N1	8	23	26	
N2	11	43	47	
M				0.719
M0	94	91	92	
M1	6	9	8	
Preoperative chemoradiation	18	27	21	0.470
Planned surgical procedure				0.021 (TaTME vs. LaTME, *P* = 0.067; TaTME vs. OpTME, *P* = 0.008; LaTME vs. OpTME, *P* = 0.397)
LAR	63	75	80	
APE or Hartmann	37	25	20	

LAR low anterior resection, *APE* abdominoperineal excision

Overall surgical success, based on a composite of negative CRM and DRM plus complete or nearly complete TME specimen, was comparable among the groups ($P = 0.174$). The highest percentage of surgical success was achieved in the TaTME group and the lowest percentage in the LaTME group (TaTME = 82%; LaTME = 71%; OpTME = 78%).

The difference in the number of retrieved lymph nodes was statistically significant among the groups ($P = 0.003$). A fewer number of lymph nodes were retrieved in the OpTME than the other two groups (TaTME vs. LaTME, $P = 0.889$; TaTME vs. OpTME, $P = 0.003$; LaTME vs. OpTME, $P = 0.018$). Pathological T status was significantly different among the groups ($P = 0.004$). Paired analysis showed a

Table 2 Pathological results

	TaTME (100)	LaTME (100)	OpTME (100)	*P* value
Specimen quality, no.				0.041 (TaTME vs. LaTME, $P=0.016$; TaTME vs. OpTME, $P=0.082$; LaTME vs. OpTME, $P=0.750$)
Complete	58	68	68	
Nearly complete	28	12	15	
Incomplete	14	20	17	
CRM involvement	7	13	10	0.368 (TaTME vs. LaTME, $P=0.157$; TaTME vs. OpTME, $P=0.447$; LaTME vs. OpTME, $P=0.560$)
DRM involvement	0	1	1	0.604
CRM, mean ± SD, mm	8.99 ± 7.21	9.44 ± 7.86	9.57 ± 7.49	0.849
DRM, mean ± SD, mm	25.18 ± 14.34	24.95 ± 16.18	30.83 ± 21.91	0.052 (TaTME vs. LaTME, $P=0.995$; TaTME vs. OpTME, $P=0.065$; LaTME vs. OpTME, $P=0.052$)
DRM for LAR subgroup, mean ± SD, mm	22.22 ± 12.73	24.08 ± 15.136	34.76 ± 23.577	<0.001 (TaTME vs. LaTME, $P=0.826$; TaTME vs. OpTME, $P<0.001$; LaTME vs. OpTME, $P=0.002$)
Successful resection, no.	82	71	78	0.174
Retrieved LNs, mean ± SD, no.	22.32 ± 8.94	21.75 ± 10.98	17.92 ± 9.29	0.003 (TaTME vs. LaTME, $P=0.889$; TaTME vs. OpTME, $P=0.003$; LaTME vs. OpTME, $P=0.018$)
Number of positive LNs, mean ± SD	1.23 ± 2.78	1.46 ± 3.33	2.22 ± 4.57	0.134
Tumor status				0.004 (TaTME vs. LaTME, $P=0.355$; TaTME vs. OpTME, $P=0.004$; LaTME vs. OpTME, $P=0.298$)
T0[a]	4	4	3	
T1	8	2	2	
T2	36	33	19	
T3	48	54	67	
T4	4	7	9	
Lymph node status				0.213
N0	69	67	57	
N1	19	20	26	
N2	12	13	17	

CRM circumferential resection margin, *DRM* distal resection margin, *LAR* low anterior resection, *LNs* lymph nodes

[a]Either complete pathological response or no tumor found after salvage surgery

significant difference only in the OpTME group compared to the TaTME group (TaTME vs. LaTME, $P=0.355$; TaTME vs. OpTME, $P=0.004$; LaTME vs. OpTME, $P=0.298$). A larger number of T3 tumors were found in the OpTME group. Pathological lymph node status was comparable among the groups ($P=0.213$).

Intraoperative results

Intraoperative outcomes are summarized in Table 3. The number of sphincter-saving procedures was comparable among the groups ($P=0.876$). However, the number of planned anastomoses was higher in the OpTME group than in the TaTME group, and the difference was statistically significant ($P=0.008$), as shown in Table 1. A number of APE procedures in the LaTME and OpTME groups were rescue procedures at the rates of 0, 9, and 14% in the TaTME, LaTME, and OpTME groups, respectively. The method of performing the anastomosis was significantly different among the groups ($P=0.044$), with higher rates of side-end anastomosis observed in the OpTME group (TaTME vs. LaTME, $P=0.890$; TaTME vs. OpTME, $P=0.022$; LaTME vs. OpTME, $P=0.015$).

The number of procedures that required mobilization of the splenic flexure of the colon was comparable among the groups ($P=0.106$). Intraoperative blood loss was significantly larger in the OpTME group than the other two groups, and was least in the TaTME group (TaTME vs. LaTME, $P=0.014$; TaTME vs. OpTME, $P<0.001$; LaTME vs. OpTME, $P<0.001$). None of the TaTME procedures were converted to open surgery, while 11 patients in the LaTME group underwent conversion ($P<0.001$), and the reason for conversion was mentioned to be difficult dissection in the lower pelvis. The operation time differed among the groups, and the difference was statistically significant ($P<0.001$), with TaTME being the fastest. The difference was not

Table 3 Intraoperative results

	TaTME (100)	LaTME (100)	OpTME (100)	*P* value
The performed procedure				0.876
LAR	63	66	66	
Intersphincteric APE	37	34	34	
Anastomotic method, no. (%)				0.044 (TaTME vs. LaTME, $P=0.890$; TaTME vs. OpTME, $P=0.022$; LaTME vs. OpTME, $P=0.015$)
Side-end	54 (85.7)	56 (84.8)	64 (97.0)	
End-end	9 (14.3)	10 (15.2)	2 (3.0)	
Splenic flexure mobilization	29	17	27	0.106
Splenic flexure mobilization in LAR, no.	24	17	26	0.192
Blood loss, mean ± SD, ml	82.10 ± 108.20	238.87 ± 355.15	704.50 ± 561.95	< 0.001
Conversion to open procedure	0	11		< 0.001
Intraoperative complications				0.693
Total, no.	13	12	16	
Bowel perforation	2	10	8	
Bleeding	8	2	6	
Urethral injury	1			
Urinary bladder injury	2		1	
Splenic injury			1	
Bowel perforation, tumors ≤ 6 cm from the anal verge, no.	1	3	4	0.304
Operation time, mean ± SD, min	284.99 ± 67.25	334.30 ± 84.31	325.25 ± 60.02	< 0.001

APE abdominoperineal excision, *LAR* low anterior resection

statistically significant between the LaTME and OpTME groups (TaTME vs. LaTME, $P<0.001$; TaTME vs. OpTME, $P<0.001$; LaTME vs. OpTME, $P=1.000$).

Intraoperative complications occurred in 41 patients (13.7%), and the rates of significant complications did not differ significantly among the groups ($P=0.693$). A larger number of intraoperative bowel perforations occurred in the LaTME and OpTME groups, though the difference of perforation rate did not reach statistical significance ($P=0.062$). Perforation rates in patients with tumors ≤ 6 cm from the anal verge were also comparable ($P=0.304$). Urethral injury, which is probably the only TaTME-specific complication, occurred in one patient (1%).

Postoperative course and complications

The postoperative outcomes are listed in Table 4. Complications are graded according to the Clavien–Dindo classification [19].The difference in 30-day mortality was not statistically significant among the three groups ($P=0.407$). The rate of anastomotic leakage was the highest in the OpTME group and the lowest in the TaTME group ($P=0.051$). The difference reached statistical significance when the TaTME group was compared to the OpTME group (TaTME vs. LaTME, $P=0.231$; TaTME vs. OpTME, $P=0.016$; LaTME vs. OpTME, $P=0.201$). Anastomotic leakages that necessitated colostomy occurred in two patients in the TaTME group (3.2%). This was lower than the leakage rates in the other two groups [three patients in the LaTME group (4.5%) and four patients in the OpTME group (6.0%)]. Groups were comparable regarding this outcome ($P=0.737$). A larger number of patients in the LaTME group suffered from urinary dysfunction, though the difference between the three groups was not statistically significant ($P=0.179$). Groups were comparable regarding the rates of stoma complications, postoperative bowel obstruction, and wound infection ($P=0.709$, $P=0.063$, and $P=0.244$, respectively). Hospital stay was the longest in the OpTME group and the shortest in the TaTME group, and the difference was statistically significant ($P=0.002$). Between-group comparisons showed a statistically significantly shorter hospital stay in the TaTME group when compared with the other two groups. The difference was not significant between the LaTME and OpTME groups (TaTME vs. LaTME, $P=0.002$; TaTME vs. OpTME, $P<0.001$; LaTME vs. OpTME, $P=0.719$). Readmission rate was significantly higher in the LaTME group ($P=0.049$), and paired comparisons showed a significant difference only between the LaTME and TaTME groups (TaTME vs. LaTME, $P=0.044$; TaTME vs. OpTME, $P=0.879$; LaTME vs. OpTME, $P=0.484$). Causes for readmission related in all groups mainly to postoperative complications and in some cases to dehydration due to high stoma production. Postoperative mortality did not differ among the groups and deaths were not related to surgery.

Table 4 Postoperative course and complications

	TaTME (100)	LaTME (100)	OpTME (100)	*P* value
Anastomotic leakage, no./no. of anastomoses (%)	6/63 (9.5)	11/66 (16.7)	17/66 (25.8)	0.051 (TaTME vs. LaTME, $P=0.231$; TaTME vs. OpTME, $P=0.016$; LaTME vs. OpTME, $P=0.201$)
Grade 3a	4	8	8	
Grade 3b	2	2	7	
Grade 4a		1	2	
Urinary dysfunction on discharge, no.	19	27	22	0.179 (TaTME vs. LaTME, $P=0.179$; TaTME vs. OpTME, $P=0.517$; LaTME vs. OpTME, $P=0.446$)
Stoma complications				0.709
Total no.	4	2	3	
Grade 1				
Grade 2	2	1		
Grade 3a	2			
Grade 3b		1	3	
Mechanical bowel obstruction				0.063
Total no.	1	8	5	
Grade 2		1	1	
Grade 3b		7	4	
Grade 4a	1			
Wound infection				0.244
Total no.	6	13	10	
Grade 1	2	4	2	
Grade 2	1	4	2	
Grade 3a	3	2		
Grade 3b		3	6	
Hospital stay, mean ± SD, days	8.63 ± 6.20	14.23 ± 15.67	15.51 ± 11.14	0.002 (TaTME vs. LaTME, $P<0.001$; TaTME vs. OpTME, $P<0.001$; LaTME vs. OpTME, $P=0.719$)
Readmission, no.	14	28	20	0.049 (TaTME vs. LaTME, $P=0.044$; TaTME vs. OpTME, $P=0.879$; LaTME vs. OpTME, $P=0.484$)
30-days mortality, no.	2	4	2	0.407

Discussion

Results of the present case-matched comparative study of three surgical procedures for the treatment of mid and low rectal cancer suggest that TaTME has some advantages. The procedure showed some superiority over LaTME and OpTME in terms of favorable specimen quality and lower rates of involved resection margins, and provided a higher rate of successful TME surgery. Furthermore, TaTME offered the highest chance of performing anastomosis when this was planned and it abolished the need for conversion to open surgery, without increasing rates of overall intraoperative complications. Despite being performed as one-team approach, the mean operation time was shorter for TaTME and the procedure resulted in comparable rates of postoperative complications and significantly shorter duration of hospital stay.

Although this study was not randomized, it represents experience from a large-volume colorectal center where TaTME is standardized. Dedicated, highly skilled, experienced, and certified colorectal surgeons performed the surgeries. The risk of selection bias was minimized through a case-matched study design. The risk of surgeon's preference for a particular procedure was eliminated in our study, as all three procedures were performed in periods where the particular type of surgery was the standard of care. At our unit, TME surgery for rectal cancer was adopted in the last two decades, and was performed as OpTME, followed by the gradual adoption of LaTME around the year 2005. TaTME is also well implemented at this time, and all the new comers with mid and low rectal cancer undergo TaTME if the tumor is assessed to be surgically removable. We have published our initial results of 25 cases [13]. The quality of data collection for this analysis was satisfactory, as most were collected prospectively in the form of a maintained database of patients undergoing TaTME, and the prospectively reported data to the clinical database of the DCCG. Intraoperative and postoperative outcomes, as well as pathological outcomes were collected from the review of electronic patient charts.

In this study, we have focused on the surrogates of the oncological quality, in the form of involved CRM and DRM, as well as the macroscopic quality of the TME specimen. The pathologist's assessment of these parameters is well standardized and its outcomes are a direct result of the quality of surgery. Poor pathological outcomes are associated with higher chances of local recurrence and metastatic disease [18]. We have calculated the percentage of successful surgery, based on a novel composite measure [5], to allow some form of comparison with the available literature. We have chosen to include "nearly complete" specimen quality combined with "complete specimen," as suggested by Fleshman et al. [5]. In another randomized trial that compared laparoscopic rectal cancer surgery with open surgery by Stevenson et al. [6] with a similar protocol, the composite outcome did not count "nearly complete" specimen as surgical success. Both randomized trials have concluded that laparoscopic surgery for rectal cancer failed to meet the "non-inferiority" criterion for successful resection, compared to open approach. Thus, the routine use of laparoscopy to treat rectal cancer could not be recommended based on results from these two recent randomized clinical non-inferiority trials. In both trials, the quality of surgery was rather satisfactory. The successful surgery was, in one study [5], accomplished in 81.7 and 86.9% of patients in the laparoscopic and open resection groups, and in the second trial [6] 82 and 89% in the laparoscopic and open resection groups, respectively. In the present study, TaTME resulted in a higher percentage of successful TME surgery, although the difference was not statistically significant. However, the quality of surgery in our study was not as high as in the above trials. A significantly lower percentage of TME specimens were incomplete in the TaTME group than in the LaTME and OpTME groups, although a higher percentage of TME specimens were nearly complete. Our results are in accordance with findings from several randomized trials, which have shown comparable rates of specimen incompleteness between laparoscopic and open surgeries [5–7, 20]. According to a study by Bulow et al. [21], CRM involvement was found in 18% of patients treated for low rectal cancer. The study was based on the DCCG database. We found lower rates of CRM involvement in the TaTME group, though the difference did not reach statistical significance. Several randomized trials have shown that laparoscopic and open surgeries for rectal cancer had similar rates of involved margins [4–7, 22, 23]. Compared to laparoscopic surgery, results of these two parameters (specimen quality and involved margins rates) have been shown to be comparable in some initial series [13, 24–27]. In the present study, rates of TME completeness were lower than those reported in the literature after TaTME. One explanation could be related to the standard method of transanal specimen extraction in our unit, which could result in minor defects rendering TME specimens "nearly complete," The 7% rate of involved CRM is also higher than the rates of involved margins reported after TaTME, including our own initial experience [13, 28]. The rate of CRM involvement in our present study is however comparable to that of laparoscopic surgery, reported in the literature [5, 6, 28].

One important advantage of TaTME is the precise selection of the distal margin, which is reflected in this study. The DRM was free in all patients in the TaTME group, while one patient in each of the other two groups had involved DRM. Another potential advantage is related directly to the ability to dissect in the deep pelvis. This can explain the absence of rescue APE procedures in the TaTME group in our study, while a significant number of patients in the other two groups had rescue APEs.

The shorter operation time in the TaTME group is in accordance with our own previous publication [13]. In earlier studies, the shorter operation time correlated with TaTME was a direct consequence of the two-team operation technique consisting of a simultaneous laparoscopic and transanal dissection (push me-pull you principle), which has the advantage of being efficient and quick. The improved operation time reflects probably the increasing expertise of the colorectal surgeons in our unit during the last few years. In our study, none of the TaTME procedures were converted to open surgery, while 11 patients in the LaTME group underwent conversion. This significant difference substantiates the theory of TaTME easing the technical difficulties in the dissection in the narrow pelvis. Rates of intraoperative complications were comparable among the groups. However, serious complications like urethral injury call for caution when TaTME is adopted. We had one case of urethral injury during the transanal part of a TaTME procedure. The complication occurred in a male patient with an advanced low rectal cancer. The patient was treated by preoperative neoadjuvant chemoradiation. Urethral injury is reported in the literature during the early years of TaTME adoption [29]. Bowel perforation rate was lower in the TaTME group. One reason could be the difficulty in dissection and instrumentation during the last part of the procedure in the LaTME and OpTME approaches. While this difficult part is performed from below in TaTME, this ensures probably a better view that improves the dissection technique. Intraoperative perforation rate in low rectal cancer surgery was reported to be 10% in a Danish study based on DCCG data [30].

Anastomotic leakage is a serious complication and occurred in rates of up to 26.7% after rectal cancer surgery, according to the latest annual report of the DCCG [31] and

12% according to a study based on DCCG database [14]. Compared to reports in the literature, anastomotic leakage rate in the TaTME in this study can be considered acceptable [32]. Leakage rates are however higher than those reported in the most recent studies that include laparoscopic and open approaches [5, 6]. One explanation for the falling leakage rates in our unit could be the improved anastomotic technique itself in TaTME procedure. We did not study the sexual and urinary functions systematically. However, urinary function based on whether patients were discharged with catheter or not was comparable among the groups.

Limitations of our study are mainly related to non-randomization and the retrospective data collection for some variables in the control groups. With the OpTME as the procedure considered the gold standard that improved the quality of rectal cancer surgery [1–3], pathological outcomes of minimally invasive surgery should be evaluated against OpTME. Indeed, minimally invasive colorectal surgery has proven short-term benefits in terms of earlier recovery and long-term benefits in terms of lower hernia and adhesion formation; hence, the shift towards OpTME does not seem to be an option. Furthermore, short-term benefits and pathological outcomes have been shown to be similar to OpTME [4]. However, rectal cancer surgery is challenging, especially the lowermost part of the pelvis where, despite improved visualization in laparoscopic surgery, colorectal surgeons still encounter difficulties due to the use of rigid instruments with limited ability to maneuver and perform precise dissection and bowel transection. Robotic surgery could solve some of these problems and the evidence supporting its safety and feasibility in rectal cancer surgery is growing, with proven lower conversion rates and similar pathological results to laparoscopic rectal cancer surgery [33, 34]. Results of the clinical randomized trial Robotic OR Laparoscopic Anterior Rectal Resection (ROLARR) [35] are to be awaited. TaTME emergence in the last few years can probably solve some of the problems encountered during standard laparoscopy [10]. The publication list is growing and the results show consistently favorable short-term results, though full implementation of TaTME needs caution due to possibly higher morbidity during the initial phase of adoption [12, 28, 36, 37]. Although designed as a non-inferiority trial, the ongoing COLOR III [38] comparing TaTME to LaTME is expected to provide the evaluation of the new approach to rectal cancer. While the results of these trials evaluating transanal and robotic approaches are awaited, we believe that our study provides evidence from the daily clinical practice.

Conclusion

In conclusion, some of the limitations of laparoscopic rectal cancer surgery seem to be overcome through the adoption of the transanal approach. TaTME had, in our hands, some obvious benefits over other approaches in terms of the operation time, blood loss, and higher rates of sphincter-saving procedures. However, the pathological results were not significantly superior to LaTME and OpTME. The procedure is, however, feasible and safe. Further studies are needed to evaluate the quality of life, genitourinary function, fecal incontinence, and the evaluation of low anterior resection syndrome in patients undergoing TaTME. In addition, research-based modifications of the instrumentation used in TaTME are warranted to reduce pitfalls and complications.

Compliance with ethical standards

Conflicts of interest Drs. Sharaf Karim Perdawood, Benjamin Sejr Thinggaard, and Maya Xania Bjoern have no conflicts of interest or financial ties to disclose.

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