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Conventional open versus transumbilical laparoscopic excision of Meckel's diverticulum (TULEM) in children: A comparative Study

Erol Basuguy*[1], Mustafa Azizoglu[2,3], Serkan Arslan[1], Tahsin Onat Kamci[4], Mustafa Atan[1], Hakkari Aydogdu[5], Bahattin Aydogdu[6], Mehmet Hanifi okur[6]

[1]*Department of Pediatric Surgery, Dicle University, School of Medicine, Diyarbakir, Türkiye*
[2]*Department of Pediatric Surgery, Basaksehir Cam and Sakura City Hospital, Istanbul, Türkiye*
[3]*Department of Stem Cell and Tissue Engineering, Istinye University, Istanbul, Türkiye*
[4]*Department of Pediatric Surgery, Tatvan State Hospital, Bitlis, Türkiye*
[5]*Department of Pediatric Surgery, Istanbul University, School of Medicine, Istanbul, Türkiye*
[6]*Department of Pediatric Surgery, Balikesir University, School of Medicine, Istanbul, Türkiye*

ABSTRACT

Aim: To evaluate the feasibility and effectiveness of the recently adopted laparoscopic-assisted technique for Meckel's diverticulum excision at our center by comparing it with our previous open surgical experience.

Methods: This study is based on a retrospective analysis of patients who underwent surgery for Meckel's diverticulum at our clinic between January 1, 2010, and May 1, 2023. Patients were divided into two groups: open excision (Group OT) and laparoscopic excision [Group CL, including three-port and transumbilical laparoscopic excision of Meckel's diverticulum (TULEM) techniques]. The study analyzed demographics, diverticulum characteristics, surgical methods, and complications. A PICO (Population, Intervention, Comparison, Outcome) framework evaluated patients under 18, comparing open and laparoscopic techniques, focusing on complications and risk factors for bowel resection.

Results: The final analysis included 95 patients (79 open and 16 laparoscopic), with a median age of 4 (1;10) years. TULEM was used in 81% of Group CL. Wedge resections accounted for 59%, and complications occurred in 6.3%. Isolated MD symptoms were more common in Group CL (87.5%, $p<0.001$), while secondary diseases prevailed in Group OT (65.8%, $p<0.001$). Resected bowel length and diverticulum characteristics showed no significant differences between groups ($p>0.05$). Secondary diseases significantly predicted increased bowel resection length ($p=0.040$), but no variable significantly predicted complications based on regression analyses. Conversion to conventional open procedure was 0%. No complications related to laparoscopy were detected.

Conclusion: Our findings suggest that the TULEM is a safe and feasible alternative to conventional open surgery for the management of Meckel's diverticulum in children.

Keywords: Meckel diverticulum, children, laparoscopy, transumbilical laparoscopic excision of Meckel diverticulum, TULEM.

✉ *Erol Basuguy**
Dicle University, School of Medicine, Department of Pediatric Surgery, Diyarbakir, Türkiye
E-mail: erbas.80@hotmail.com

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1. Introduction

Meckel's diverticulum (MD) is a congenital anomaly of the gastrointestinal system, occurring in approximately 1-3% of the population [1-3]. It arises from the incomplete atrophy of the omphalomesenteric duct during early embryonic development, presenting as a blind-ending pouch on the anti-mesenteric border of the ileum [4]. While most cases remain asymptomatic, some may manifest gastrointestinal bleeding, bowel obstruction, or perforation, necessitating surgical intervention [5].

Histologically, MD is typically lined by ileal mucosa; however, ectopic mucosa, most commonly gastric, may also be present, posing risks of acid secretion and complications such as ulceration or malignant transformation [6,7]. Surgical management of MD is directed to excising the diverticulum along with any associated ectopic mucosa [8]. Techniques have evolved from segmental bowel resection with primary anastomosis to laparoscopic stapler-assisted diverticulectomy. Even with advances in surgical techniques, controversy exists as to the best approach when ectopic mucosa is suspected [9,10].

Meckel's diverticulum can be excised using either open surgical techniques or laparoscopic approaches [11-14]. Among laparoscopic methods, both conventional three-port and single-port techniques are employed [15]. The literature reports the safety and efficacy of laparoscopic Meckel's diverticulum excision [15]. Typically, following laparoscopic exploration, the diverticulum is exteriorized through a trocar incision for extracorporeal excision. This study aims to evaluate the feasibility and effectiveness of the laparoscopic-assisted technique for Meckel's diverticulum excision by comparing its outcomes with our previous open surgical experience.

2. Materials and methods

2.1. Patients and groups: This study is based on a retrospective analysis of patients who underwent surgery for Meckel's diverticulum at our clinic between January 1, 2010, and May 1, 2023. Following ethical committee approval, patient records were reviewed retrospectively. Patients were categorized into two main groups: Group OT included patients who underwent open excision of Meckel's diverticulum, Group CL comprised those treated with conventional three ports laparoscopic excision or TULEM transumbilical laparoscopic excision of Meckel's diverticulum.

The analysis focused on patient demographics (age and gender), the length and base width of the diverticulum, the intestinal segment where the diverticulum was located, the presence of malrotation, intussusception, associated comorbidities, the need for a stoma post-surgery, and the surgical technique used. Data obtained was analyzed to assess these parameters.

2.2. PICO Strategy

2.2.1. Population: Patients under 18 years old.

2.2.2. Intervention: Patients underwent either conventional three ports laparoscopy or TULEM technique.

2.2.3. Comparison: Patients underwent Meckel diverticulum excision with open technique.

2.2.4. Outcome: Any complications (stoma formation, reoperation, small bowel obstruction, perforation…), risk factor analysis for bowel resection and complications

2.3. Eligibility criteria: Inclusion criteria were age between 0-18 years, a confirmed

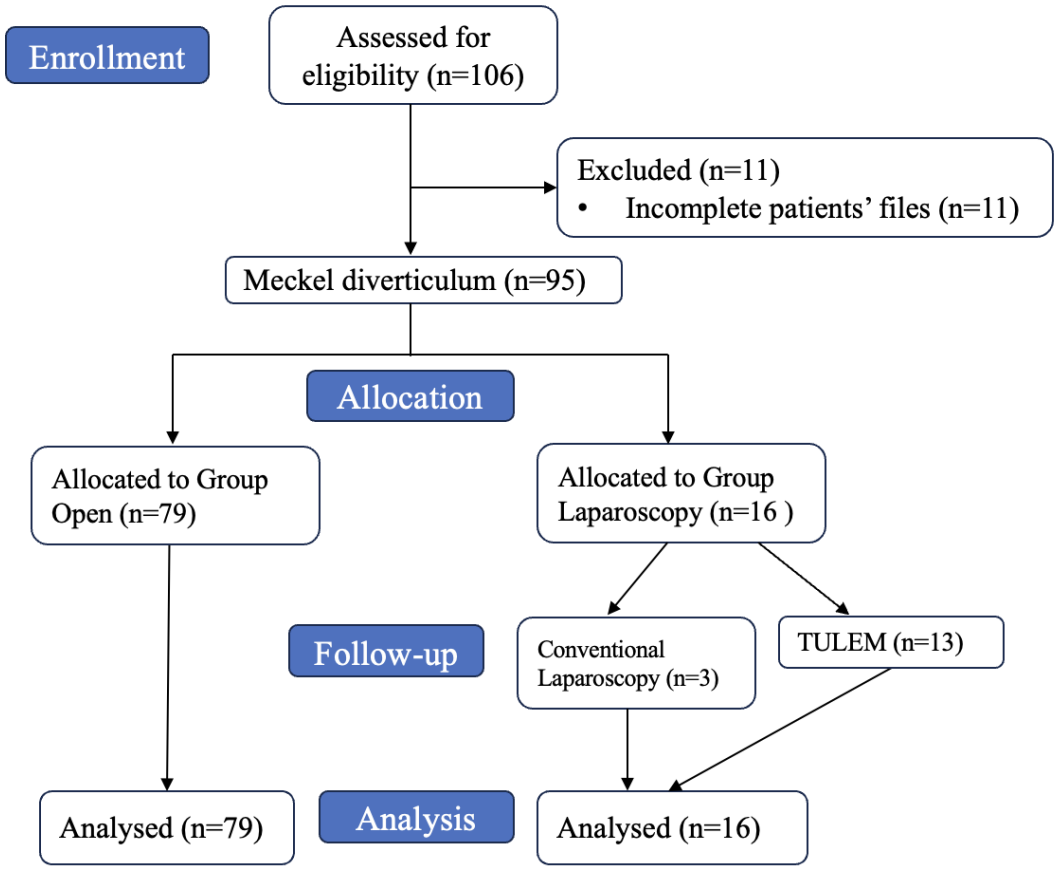

Figure 1. Flow chart of patient selection.

diagnosis of Meckel's diverticulum, treatment and diagnosis conducted at our clinic, and the availability of complete and consistent retrospective data. Exclusion criteria included patients over 18 years of age and incomplete or inconsistent retrospective records. Flow chart of patient's selections were given in Figure 1.

2.4. Surgical technique: The classical laparoscopic and open techniques were performed as described in the literature. In this section, the TULEM (Transumbilical Laparoscopic Excision of Meckel's Diverticulum) technique is explained in detail. For TULEM, the patient was placed in the supine position (Figure 2). Following umbilical preparation, abdominal entry was achieved using a Hasson technique with a 15 mm thoracoport. As previously described by Basuguy et al., a sterile surgical glove was secured as illustrated [16]. Two 5 mm standard

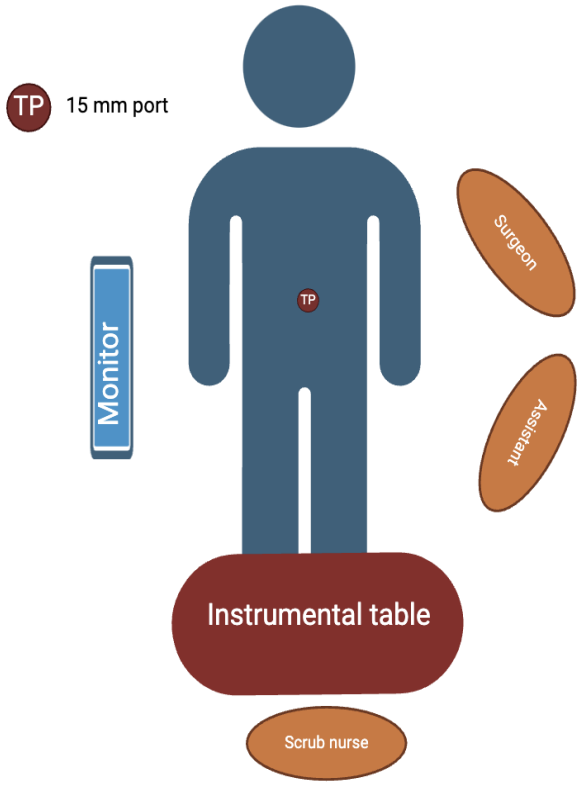

Figure 2. Patient and port position.

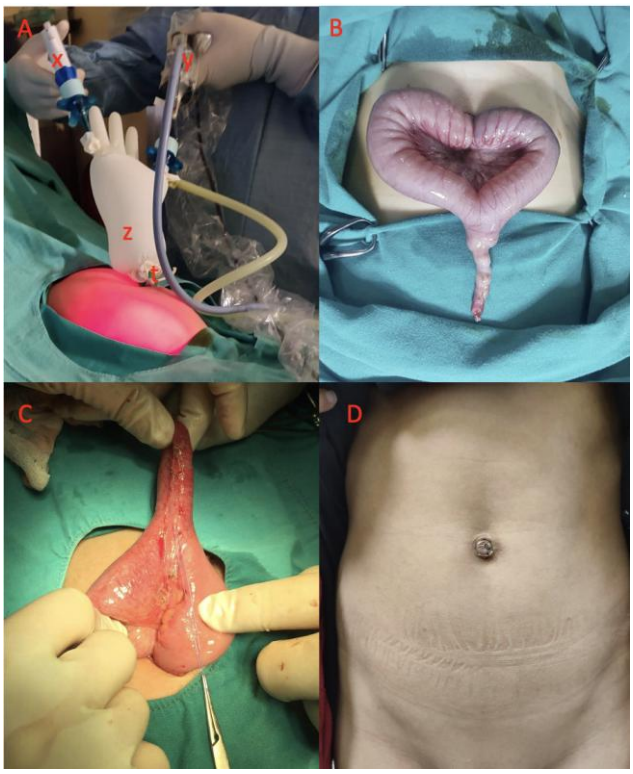

Figure 3. Intraoperative view, A: Single port created with sterile glove (x: Grasper, y: 5 mm scope, z: Glove, t: 15 mm thoracoport), B: Meckel diverticulum delivered to out through umbilical incision, C: Meckel diverticulum was separated and the allied vascular structures are ligated, D: Postoperative 14th day.

trocars were tied to the glove at the fingers farthest apart. Pneumoperitoneum was then established with CO_2 gas. Through one trocar, a 5 mm 30° scope was inserted, and a working instrument was introduced through the other. In most cases, exploration was performed using a single working instrument. If adequate exploration could not be achieved, an additional third port was introduced through the middle finger of the glove, allowing for the use of a second working instrument. Despite the limited maneuverability of the 15 mm thoracoport, sufficient working space was typically achieved for the camera and instruments. During exploration, starting from the terminal ileum and proceeding proximally, the Meckel's diverticulum was identified. Any associated bands or structures attached to the diverticulum were examined. The diverticulum was grasped with a grasper and exteriorized through the umbilical port for extracorporeal excision. As noted in the literature, wedge resection or complete resection with anastomosis was performed as required. After ensuring there were no anastomotic leaks, the bowel was repositioned into the abdomen, and pneumoperitoneum was reestablished. The abdomen was further inspected for any additional pathologies, after which laparoscopy was concluded. The umbilical port entry was closed using a single suture with a Z-technique (Figure 3).

2.5. Statistical analysis: Descriptive statistics, including frequencies and other characteristics for all categories, were conducted for patient data. Continuous variables were expressed as mean ± standard deviation, if met normal distribution. Continuous variables that did not follow a normal distribution were expressed as medians with interquartile ranges (25th and 75th percentiles) in parentheses. The normality of data distribution was assessed using the Shapiro-Wilk and Kolmogorov-Smirnov tests for continuous variables. Continuous variables with normal distribution were compared using the Student's T-test. When the data did not follow a normal distribution, non-parametric tests were chosen. Categorical variables were compared using the Chi-square test. Logistic regression analysis was conducted to evaluate risk factors. All analyses were performed using Jamovi (version 3.4.1) software. All p-values were two-tailed, and the p-value ≤ 0.05 was considered statistically significant.

A sample size of 95 was sufficient to detect effect sizes of $\delta \geq 0.5$ with a probability of at least 0.998, assuming a two-sided test with a Type I error rate of $\alpha = 0.05$.

3. Results

A total of 106 patients underwent surgery with a diagnosis of MD. However, due to the retrospective nature of the study, detailed data for 11 patients were unavailable from the patient files. Consequently, the final analysis included 95 patients, with a median age of 4 (1;10) years. Of these, 78 patients (82.1%) were male, and 17 patients (17.9%) were female. Many of the procedures were performed using an open approach (79 patients, 83.2%), while laparoscopy was employed in 16 patients (16.8%).

Among the laparoscopic cases, the TULEM technique was successfully completed in 13 patients (81%). In the remaining 3 patients (19%), the procedure initially commenced with TULEM but was transitioned to a conventional three-port technique due to minor intra-abdominal adhesions and technical difficulties. Wedge resection was the most common type of resection, performed in 56 patients (59%), while segmental bowel resection was conducted in 39 patients (41%). The median length of the resected bowel was 20 (5;30) cm, and the median distance from the diverticulum to the cecum was 50 (39;60) cm. The median length of the diverticulum was 8 (5;8) cm. Stoma creation was required in 2 patients (2.1%). Complications occurred in 6 patients (6.3%). Malrotation was identified in 2 patients (2.1%). Isolated MD symptoms were observed in 38 patients (46.9%), while 43 patients (53.1%) presented with symptoms secondary to other diseases (Table 1).

Surgical indications were broadly categorized into isolated symptomatic Meckel's diverticulum (e.g., gastrointestinal bleeding, abdominal pain) and secondary pathologies encountered during exploration. Isolated MD symptoms were observed in 41 patients (43%), while 54 patients (57%) presented with symptoms secondary to other diseases (Table 2).

Table 1. Patients' characteristics.

Parameters	**n (%)**
Age*	4 (1;10)
Gender	
Male	78 (82.1%)
Female	17 (17.9%)
Surgical approach	
Open	79 (83.2%)
Laparoscopy	16 (16.8%)
Conversion to conventional open procedure	0 (0%)
Laparoscopic technique	
TULEM	13 (81%)
Three ports	3 (19%)
Type of resection	
Wedge	56 (59%)
Segmental bowel resection	39 (41%)
Resected bowel length (cm)*	20 (5;30)
Distance to the cecum (cm)*	50 (39;60)
Diverticulum length (cm)*	8 (5;8)
Need for stoma creation	2 (2.1%)
Any complications	6 (6.3%)
Malrotation	2 (2.1%)
Isolated Meckel's diverticulum	41 (43%)
Secondary diseases	54 (57%)

** Median (Q1; Q3), TULEM: Transumbilical laparoscopic excision of Meckel diverticulum*

Table 2. Underlying diseases and surgical indications.

Secondary diseases	**n**
Intussusception	18
Appendicitis	8
Adhesive small bowel obstruction	8
Volvulus	5
Omphalocele	3
Malrotation	2
Ileal atresia	2
Meckel diverticulitis	3
Meckel diverticulum perforation	5
Internal hernia	1

The median age was similar between groups (1.5 years for laparoscopy vs. 5 years for open, *p*=0.291). There were no significant differences in gender distribution, type of resection, resected bowel length, distance to the cecum, diverticulum length, or stoma creation rates between the two groups (all $p > 0.05$). Complications occurred exclusively in the open surgery group (7.6%), though this difference was not statistically significant (*p*=0.255). Isolated Meckel's Diverticulum symptoms were significantly more common in the laparoscopy group (87.5% vs. 34.2%, *p*<0.001), whereas secondary diseases were more prevalent in the open surgery group (65.8% vs. 12.5%, *p*<0.001) (Table 3).

Table 3. Laparoscopy versus open resection of Meckel's diverticulum.

Parameters	Laparoscopy (n=16)	Open (n=79)	*p*-value
Age*	1.5 (1;9.25)	5 (1;10.5)	0.291
Gender			0.537
Male	14 (87.5%)	64 (81%)	
Female	2 (12.5%)	15 (19%)	
Type of resection			0.810
Wedge	9 (56.3%)	47 (59.5%)	
Segmental bowel resection	7 (43.8%)	32 (40.5%)	
Resected bowel length (cm)*	5 (5;6)	20 (5;30)	0.305
Distance to the cecum (cm)*	50 (40;55)	50 (40;60)	0.609
Diverticulum length (cm)*	6.5 (5;11)	8 (5;8)	0.387
Isolated Meckel's diverticulum	14 (87.5%)	27 (34.2%)	<0.001
Secondary diseases	2 (12.5%)	52 (65.8%)	
Malrotation	0 (0%)	2 (2.5%)	0.520
Need for stoma creation	0 (0%)	2 (2.5%)	0.520
Any complications	0 (0%)	6 (7.6%)	0.255
Small bowel obstruction	0 (0%)	4 (5.%)	0.358
Any complication related laparoscopy	0 (0%)	-	-
Anastomotic leak	0 (0%)	0 (0%)	1.000
Wound infection	0 (0%)	0 (0%)	1.000

** median (Q1;Q3), MD: Meckel diverticulum*

A linear regression model was tested to evaluate variables for predicting bowel resection length. The linear logistic regression model showed that age (estimate= -1.26, *p*=0.101), laparoscopic approach (estimate= -15.3, p=0.305), and distance to the cecum (estimate= -0.213, *p*=0.362) were not significant predictors of bowel resection length. The presence of secondary diseases (estimate=22, *p*=0.040) was significantly associated with an increased bowel resection length. The length of the diverticulum was not applicable in the model (Table 4).

The binary logistic regression model for predicting any complications (stoma formation) showed no statistically significant associations for age (*p*=0.384), surgical approach (laparoscopy vs. open), type of resection (segmental vs. wedge), resected bowel length (*p*=0.886), distance to the cecum (*p*=0.859),

diverticulum length (p=0.955), or secondary diseases (p=0.995). No variable was identified as a significant predictor of complications in this model (Table 5).

Table 4. Regression model for prediction bowel resection length.

Variables	Estimate	*p*-value
Age	-1.26	0.101
Laparoscopic (ref: open)	-15.3	0.305
Distance to the cecum (cm)	-0.213	0.362
Diverticulum length (cm)	N/A	N/A
Any complication (ref: no complication)	1.861	0.905
MD secondary (ref: isolated)	22	0.040

MD: Meckel diverticulum.

Table 5. Binary logistic regression model for prediction any complication.

Variables	Estimate	OR	*p*-value
Age*	0.06	0.93	0.384
Gender (ref: Female)	17.13	N/A	0.995
Surgical approach (ref: Open)	17.07	N/A	0.995
Type of resection (ref: Wedge)	-18.4	N/A	0.994
Resected bowel lenght (cm)*	-0.01	0.98	0.886
Distance to the cecum (cm)*	0.004	1	0.859
Diverticulum length (cm)*	-0.13	0.98	0.955
Need for stoma creation	-20.67	N/A	0.994
Malrotation	N/A	N/A	N/A
MD secondary (ref: isolated)	-18.3	N/A	0.995

MD: Meckel diverticulum, N/A: Non-applicable.

4. Discussion

In our study comparing conventional open surgery and TULEM in children, key findings highlighted the safety and efficacy of TULEM as an alternative to open surgery. Complications occurred exclusively in the open group, albeit not significantly. Isolated Meckel's diverticulum cases were more frequently managed laparoscopically, whereas patients presenting with secondary diseases predominantly underwent open surgery. Furthermore, no significant differences were observed in resected bowel length, diverticulum characteristics, or overall complication rates between the surgical groups. In the pediatric population, Meckel's diverticulum is relatively rare and is often asymptomatic. It typically contains heterotopic tissue, most commonly gastric mucosa and pancreatic cells [1,7,8,17,18]. Gastrointestinal bleeding is the most frequently reported symptom. Other common symptoms include abdominal pain, vomiting, and nausea [1,2]. The presenting complaints may consist of primary symptoms; however, they can also arise due to underlying secondary conditions. These secondary conditions may include appendicitis, intussusception, volvulus, perforation of Meckel's diverticulum, or omphalocele [1,2]. In the largest patient series, the proportion of symptomatic Meckel's diverticulum ranges from 9.0% to 71.1% of all resected specimens [2,17,18]. Ueberrueck et al. reported that 9% of cases in their large series of 233 patients were symptomatic, which included a significant number of silent Meckel's diverticula [17]. Among the pediatric series, 46.7% of children presented with obstruction, 25.3% with gastrointestinal hemorrhage, and 19.5% with inflammation [2,11]. Alemayehu et al, analyzing the Pediatric Hospital Information System Database, found that 60.1% of children with symptomatic Meckel's presented with obstruction, 35.6% with gastrointestinal hemorrhage, and 8.4% with inflammation [2,11]. In our study, secondary diseases were identified in 55 patients, with intussusception being the most common (18 cases), followed by appendicitis and adhesive bowel obstruction (8 each), volvulus (n=5), perforation (n=5), and omphalocele (n=3).

Meckel's diverticulum is typically cone-shaped and most located within the final 90 cm of the terminal ileum [1,2,18]. In our study, the average distance of the Meckel's diverticulum from the cecum was 50 cm (range: 39–60 cm). The length of the diverticulum varies between 1 and 10 cm and can sometimes resemble the vermiform appendix, being tubular with a narrow base [1,18]. In our study, the length of Meckel's diverticulum ranged from 3 to 8 cm.

Meckel's diverticulum can be treated surgically using either open or laparoscopic approaches in symptomatic patients [14,15]. Laparoscopic treatment of Meckel's diverticulum was first described by Attwood et al., who used a linear stapler device to perform a laparoscopic-assisted diverticulectomy [19]. Laparoscopic excision of Meckel's diverticulum may be performed either as a fully laparoscopic procedure or as a laparoscopic-assisted technique involving extracorporeal resection of the MD. In a study of 55 patients with Meckel's diverticulum, Duan et al. treated patients using two different laparoscopic techniques: 41 patients underwent a fully laparoscopic procedure, while 14 underwent a laparoscopic-assisted approach (20). Shalaby et al. performed Meckel's diverticulectomies using both fully laparoscopic and laparoscopic-assisted approaches, completing 18 and 12 cases, respectively [21]. Conversely, Chan et al. performed extracorporeal laparoscopic-assisted Meckel's diverticulectomies on 18 patients [22].

The use of intracorporeal stapling in fully laparoscopic diverticulectomies can reduce operative time, but increased occurrence of small bowel adhesion and incomplete resection rate [23]. However, transumbilical laparoscopy combined with extracorporeal diverticulectomy offers the option of a handsewn technique. In our study, we employed an extracorporeal laparoscopic-assisted technique for all cases in Group CL.

While laparoscopy has demonstrated safety comparable to the open approach, along with advantages such as reduced hospital stays and lower costs, there are still challenges that need to be addressed [11]. Firstly, if a fully intracorporeal procedure is performed with stapler use, incomplete resection of the gastric mucosa may occur. In our study, all cases were performed extracorporeally, and we achieved complete mucosal resection with handsewn anastomoses, thereby avoiding the risk of bleeding from residual mucosa. Secondly, although laparoscopy is generally safe and feasible, large database reports from the NSQIP database indicate a conversion rate of approximately 30% [24]. This is primarily attributed to technical difficulties, the learning curve, intra-abdominal adhesions, and wide-based Meckel's diverticula. However, our study reported a 0% conversion to conventional open procedure rate. It is important to note that the majority of our Group CL cases were primary cases without underlying secondary diseases. Despite this, we believe that TULEM provides an optimal field of view and low conversion to conventional open procedure rates in appropriately selected patients.

4.1. Limitations: This study has several limitations. Firstly, the retrospective design is susceptible to inherent biases, including selection bias and recall bias. As the data relied on existing medical records, there are potential issues with incomplete or inconsistent information. Secondly, the relatively small sample size, particularly in the laparoscopic group, may affect the generalizability of the findings and limit the statistical power for broader populations. Thirdly, as a single-center study, the results may not be reflective of practices at other institutions or different patient

populations. Furthermore, most laparoscopic cases were primary cases, which might not be representative of more complex cases with underlying secondary diseases.

4.2. Conclusions: In conclusion, our findings suggest that the TULEM is a safe and feasible alternative to conventional open surgery for the management of Meckel's diverticulum in children. While it offers a minimally invasive option, the current data are insufficient to claim that it is definitively superior or equivalent to open surgery. More comprehensive, large-scale prospective studies evaluating long-term postoperative recovery, detailed operative outcomes, and other clinically meaningful endpoints are necessary to determine the optimal surgical approach.

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Ethical Statement: *The protocol was approved by the Clinical Research Ethics Committee of Dicle University (approval no. 2023/171; 17 May 2023), and written informed consent was obtained from all participants or their legal representatives.*

Patient Consent Statement

Written informed consent was obtained from all participants prior to enrollment in the study.

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