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Optimizing Surgical Resection of the Bleeding Meckel Diverticulum in Children

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Abstract

Purpose—Meckel diverticula containing gastric heterotopia predispose to local hyperacidity, mucosal ulceration, and gastrointestinal bleeding in children. Eradication of acid-producing oxyntic cells is performed by either of two surgical methods: segmental enterectomy including the diverticulum or diverticulectomy only.

Methods—Retrospective review of all children having surgical resection of a Meckel diverticulum at a tertiary-referral children's hospital from 2002–2016 was performed. Demographic data, surgical method, pathological specimens, and outcomes were evaluated.

Results—102 children underwent surgical resection of a Meckel diverticulum during the study period. 27 (26.5%) children presented with bleeding, of which 16 (59%) had diverticulectomy only, and 11 (41%) had segmental ileal resection. All Meckel diverticula in children presenting with bleeding contained gastric heterotopia, and resection margins were free of gastric mucosa. Histologically, 19 specimens showed microscopic features of ulceration, on average 2.95 mm (SD 4.49) from the nearest gastric mucosa (range: 0–16 mm). Mean length of hospitalization after ileal resection was 4.0 days (SD 1.2) compared to 1.6 days (SD 0.9) for diverticulectomy only ($p < 0.001$), with no re-bleeding occurrences.

Conclusion—In the operative management of children having a bleeding Meckel diverticulum, diverticulectomy-only completely eradicates gastric heterotopia without increased risk of continued bleeding or complications and significantly shortens hospitalization.

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LEVEL OF EVIDENCE

Treatment Study: Level III

Keywords

Meckel diverticulum; gastric heterotopia; gastrointestinal bleeding; laparoscopic diverticulectomy

1. INTRODUCTION

Meckel diverticulum is an outpouching of the mid-ileum that develops as a result of an incompletely obliterated omphalomesenteric, or vitelline, duct.¹ The prenatal yolk stalk investing the omphalomesenteric duct typically regresses between the fifth and seventh weeks of fetal life. Errors in the coordination of this yolk stalk regression can lead to variable entrapment of primordial intestinal tissue and ileal anomalies. Indeed, an omphalomesenteric duct will persist in approximately 2% of the population forming a true diverticulum located typically 45–60 cm proximal to the ileocecal valve.^{2–4} Given its relative commonality, Johann Meckel in 1809 described this congenital diverticulum as the most prevalent anomaly of the alimentary tract.^{5, 6}

The early embryologic origin of the omphalomesenteric duct, coupled with the short length of the intestinal tract at this stage of development, implies that the duct lining will contain multipotent stem cells normally fated to become a variety of different digestive tissues but which become trapped in this vitelline remnant. Specifically, a Meckel diverticulum can contain ectopic gastric and duodenal mucosa and more rarely rests of pancreatic tissue. As a result, it has been estimated that 4–6% of individuals with a Meckel diverticulum will become symptomatic, presenting most commonly with bleeding, obstruction, diverticulitis, or perforation.^{3, 7} Specifically, Meckel diverticulum is the most common cause of small intestinal bleeding in children, occurring in a reported 31% of children with a symptomatic Meckel diverticulum.^{8, 9}

Pathologically, a Meckel diverticulum containing gastric heterotopia predisposes to local hyperacidity, mucosal ulceration, and gastrointestinal bleeding in children. Eradication of the heterotopic, acid-producing oxyntic cells is performed by either of two surgical methods: segmental enterectomy including the diverticulum or diverticulectomy only. Advocates of small bowel resection for a bleeding Meckel diverticulum may choose this therapy due to concern for heterotopic gastric mucosa at the base or within the ileum or to incorporate any potential ileal ulceration within the resection specimen.^{10–12} Alternatively, advocates of diverticulectomy-only contend that the ulcerated intestinal mucosa is immediately adjacent to the heterotopic gastric mucosa, which itself originates in the diverticulum, and that removal of this acid-producing source is sufficient to prevent further bleeding.¹³ Diverticulectomy-only has also been reported as performed in both adults and children via both an open or laparoscopic approach, and the latter may confer additional convalescent advantages.^{14–16}

Much of the controversy regarding the optimal surgical therapy for the bleeding Meckel diverticulum is due to the paucity of published data on the precise location of the ulceration and its proximity to the heterotopic gastric mucosa. Information on the location of the acid-producing cells and actual source of bleeding could assist in guiding more streamlined and higher quality surgical care.¹⁷ Our overarching hypothesis states that the acid concentration

is greatest immediately adjacent to the gastric mucosa and is buffered rapidly with increasing distance, thereby predisposing the immediately adjacent intestinal-like mucosa within the diverticulum to be the site of acid-induced ulceration. Therefore, we sought to test the specific hypothesis that diverticulectomy-only is sufficient to eliminate the ectopic acid source, ulcer, and bleeding symptoms.

2. METHODS

We reviewed retrospectively the outcomes of all children having surgical resection of a Meckel diverticulum at a tertiary-referral children's hospital between 2002–2016 to evaluate if diverticulectomy-only is sufficient treatment for bleeding Meckel diverticula. We also re-reviewed all original Meckel specimens resected for bleeding to document the presence of heterotopic gastric mucosa, measure the distance of intestinal ulceration from the nearest edge of oxyntic cells, and assess resection margins for the absence of gastric mucosa.

2.1 Subjects and Setting

The study population consisted of all children treated for a Meckel diverticulum at the Monroe Carell, Jr. Children's Hospital of the Vanderbilt University Medical Center (VUMC) in Nashville, TN from January 1, 2002 to August 31, 2016. All records containing an ICD-9 diagnosis code of 751.0 or ICD10 code Q43.0 (i.e., Meckel diverticulum) or C17.3 (i.e., Meckel diverticulum, malignant) at 18 years of age or younger were ascertained. Charts were reviewed manually by a single reviewer (JRR) with a second reviewer (HNL) involved to address uncertainty. Children were excluded if there was no mention in the attending pediatric surgeon's operative report of a visible diverticulum extruding from the ileum or pathology reports. Cases of heterotopic gastric mucosa occurring in the absence of a Meckel diverticulum were excluded. The institutional review board at VUMC approved the study and waived requirement for obtaining informed consent.

2.2 Categorization of Presenting Characteristics

All patient records were reviewed to ascertain demographic data, including age at presentation, race, and ethnicity. Records were reviewed to determine the clinical symptoms preceding operative management for the Meckel diverticulum. Bleeding was defined as bloody stools with or without a declining hemoglobin or hematocrit. Operative reports were reviewed to determine the method of surgical resection and classified as open diverticulectomy, laparoscopic diverticulectomy (Figure 1), or segmental ileal resection. Diverticulectomy-only was defined as resection of the diverticulum alone, without performing a resection of a circumferential portion of the small intestine (Figure 1). Any missing data were categorized as unknown.

2.3 Assessment of Clinical Outcomes

The main outcomes of interest included adverse events and length of hospital stay post-operatively. Adverse events were predefined as continued bleeding post-operatively (need for postoperative transfusion or continued blood in stool), surgical site infections, post-operative Emergency Department visits, hospital readmissions, respiratory distress, bacteremia, pneumonia, urinary tract infection, additional operative or interventional

radiology procedures, or other complications of treatment. All adverse events documented in the electronic medical record within 90 days of surgical resection were included in analysis. Length of hospital stay after surgery was measured as the time from surgery to discharge order. Categorical outcomes were compared using Fisher exact test and continuous variables with t-tests. All analyses were conducted in R version 3.0.1.¹⁸

2.4 Analysis of Pathology Specimens

Pathology reports of all patients having resection of a Meckel diverticulum were reviewed to determine the presence or absence of heterotopic tissue, including gastric and pancreatic. Of patients who presented with a bleeding Meckel diverticulum, hematoxylin and eosin (H&E) stained slides of the original pathology specimens were retrieved for detailed histologic re-analysis. Each specimen was analyzed specifically for the presence and location of gastric heterotopia. Pathologic margins were assessed further for the presence of gastric heterotopia. All available H&E slides from each specimen were analyzed in detail for the presence of mucosal ulceration or erosion (Figure II). If ulceration or erosion was present within the sampled specimen, the distance from gastric heterotopia to ulceration was measured microscopically in millimeters (mm). As heterotopic pancreatic tissue was unlikely to contribute to bleeding or mucosal ulceration, we did not analyze the relationship of pancreatic heterotopia to ulceration or gastric heterotopia.

3. RESULTS

3.1 Demographic Characteristics

A total of 102 patients underwent surgical resection of a Meckel diverticulum during the study period. Clinical and demographic characteristics of the entire cohort are presented in Table 1. The study population predominantly consisted of children who were white (90%) and male (75%). Overall, the two most common presenting symptoms were obstruction (n=32) and bleeding (n=27), respectively. The majority of patients (n=70; 69%) underwent diverticulectomy only, with 40 children having an open diverticulectomy and 30 laparoscopic diverticulectomy. For the entire cohort, and regardless of surgical indication, 60 children (59%) had gastric heterotopia, and 7 children (7%) had pancreatic heterotopia within the diverticulum. Those children who developed bleeding were not significantly different in age compared to other symptomatic presentations of a Meckel diverticulum (7.0 versus 8.3 years: $p=0.39$).

3.2 Clinical Outcomes of All Children Undergoing Surgery for Meckel Diverticulum

Of all children who underwent surgical resection of a Meckel diverticulum for any reason, 7 of 102 (6.9%) had a post-operative complication, none of which occurred in the bleeding sub-group. The majority (4 of 7 children) who developed a complication underwent resection of a Meckel diverticulum discovered incidentally at time of surgery for another indication (e.g., malrotation or necrotizing enterocolitis). Mean age of children who had a complication after undergoing surgical resection of an incidentally discovered Meckel diverticulum was 1.8 years. For the entire cohort, only one death occurred, that of a newborn who was operated on for obstruction secondary to intestinal malrotation who had concomitant and complex congenital cardiac anomalies that resulted in demise of the infant

on postoperative day 11. None of these complications could be directly attributed to resection of the incidentally discovered Meckel diverticulum.

The remaining 3 children who developed a post-operative complication had resection of a Meckel diverticulum for symptoms of obstruction. Of patients with obstruction, one underwent a segmental ileal resection and was the only patient in the cohort to have a post-operative anastomotic leak requiring reoperation. A single patient who underwent open diverticulectomy for obstruction secondary to volvulus had post-operative respiratory distress resulting in the need for re-intubation. Finally, one patient who underwent laparoscopic diverticulectomy for obstruction with internal hernia subsequently had a postoperative abscess requiring drainage by interventional radiology and 3 months later required reoperation for recurrent small bowel obstruction. No patients with the initial presentation of bleeding, diverticulitis, or perforation had a post-operative complication.

Of all children who underwent resection of Meckel diverticulum for any reason, 40 (40%) had open or laparoscopic-assisted diverticulectomy, 30 (29%) had laparoscopic diverticulectomy, and 32 (31%) underwent segmental ileal resection. In the overall cohort, a statistically significant difference was detected between post-operative length of hospital stay among children who underwent open versus laparoscopic diverticulectomy for any presenting symptom of the Meckel diverticulum (2.6 days [SD 1.9] versus 11.4 days [SD 23.2], $p=0.02$).

3.3 Bleeding Meckel Diverticulum Cohort

Of these 102 children with a Meckel diverticulum, 27 (26.5%) presented with bleeding symptoms prompting surgical resection (Table 2). All children who presented with symptoms of bleeding underwent a pre-operative technetium-99m pertechnetate (Meckel) scan, which detected ectopic gastric mucosa on initial scans in 24 (89%). For the children with a negative Meckel scan, all subsequently underwent an upper endoscopy and colonoscopy. Three patients had computed tomography before surgical intervention. Further, two of the patients underwent repeat Meckel scanning, which detected ectopic gastric mucosa in one of these cases on the second study.

A majority ($n=16$; 59%) of the bleeding patients had diverticulectomy only, with 11 laparoscopic and 5 open (2 laparoscopic-assisted) diverticulectomies (Figure 1). The remaining 11 children (41%) had segmental ileal resection. These two operative groups were similar at baseline (Table 2). Operations were performed by 10 surgeons with variable preferences. Four surgeons contributed to the diverticulectomy only group, 4 surgeons contributed to the segmental ileal resection group, and 2 surgeons performed both operations during the time period. Operative time for bleeding patients who underwent diverticulectomy only was on average 37 minutes shorter than the operative time for enterectomy (105.8 mins versus 142.5 mins, $p = 0.02$). Mean length of hospitalization after ileal resection was 4.0 days (SD 1.2) compared to 1.6 days (SD 0.9) for diverticulectomy only ($p < 0.001$). No statistical difference was observed in postoperative length of stay among those in the bleeding cohort who underwent a laparoscopic diverticulectomy compared to open or laparoscopic-assisted diverticulectomy ($p = 0.93$). No postoperative

bleeding, transfusion, or other complications occurred in either surgical group among children presenting with bleeding.

3.3 Pathology Specimens

After re-review of the available H&E specimens for each case, all Meckel diverticula in children presenting with bleeding contained gastric heterotopia. All resection margins were free of gastric mucosa regardless of procedure type. After re-examination of all slides that had been originally submitted from each case, 19 specimens showed microscopic features of ulceration or erosion of intestinal-like mucosa, which were measured to be on average 2.95 mm (SD 4.49) from nearest gastric tissue (range: 0–16 mm; Figure 2). The distance between the ulcer and gastric heterotopia was marginally farther in patients who underwent segmental ileal resection at 4.7 mm compared to 1.0 mm in patients who underwent diverticulectomy only ($p = 0.07$).

4. DISCUSSION

Our study shows that in the operative management of children presenting with a bleeding Meckel diverticulum, diverticulectomy-only completely resects gastric heterotopia without increased risk of continued bleeding or other complications. All resection margins, regardless of whether a diverticulectomy or segmental ileal resection was performed, were clear of gastric heterotopia. Acid-induced ulcerations appear confined to the gastric heterotopic mucosa itself or to the immediately adjacent intestinal-type mucosa of the Meckel diverticulum. Furthermore, children treated with diverticulectomy-only had shorter operative times and, on average, a hospital stay after surgery of 2.5 days fewer than children who underwent segmental ileal resection. Therefore, when technically feasible, the optimal surgical approach to the bleeding Meckel diverticulum appears to be diverticulectomy-only.

Approximately one-quarter of children undergoing diverticulectomy in this review presented with bleeding, similar to previous research.^{19, 20} Several prior studies have also shown successful resection of a Meckel diverticulum via diverticulectomy-only for children presenting with symptoms of bleeding.^{13, 15} There are advantages of this approach, including the ease of diverticulectomy with laparoscopy and elimination of the need for an enterectomy. Diverticulectomy-only can be accomplished through laparoscopy, using endostapling devices, as was performed in 11 children of our cohort who presented with bleeding.²¹ The main advantage with the use of stapling devices is definitive closure of the bowel lumen before it cuts, reducing the chance of peritoneal contamination and increasing speed of the procedure.²¹ This may account for some of the decrease in operative time amongst the children in this cohort who underwent diverticulectomy-only compared to segmental enterectomy. Although we did not see a difference in post-operative length of stay in our cohort of patients who presented with bleeding and underwent open versus laparoscopic diverticulectomy-only, it is likely that the more minimally-invasive approach of diverticulectomy compared to segmental ileal resection decreased patient recovery time and improved hospital length of stay. Another potential factor contributing to decreased post-operative length of stay is that diverticulectomy-only is performed without an enterectomy and intestinal anastomosis, thus decreasing the likelihood of post-operative ileus and

reducing the need for inpatient monitored recovery of bowel function. Some have raised concerns regarding increased cost with the use of laparoscopy or stapling devices; however, we advocate the decrease in operative time and length of hospital stay likely mitigates the increase in operating room supply expense. There are technical contraindications to diverticulectomy-only, including a thickened, broad based or very short diverticulum, resulting in the risk of incorporation of too much ileum and potential stenosis through diverticulectomy-only.^{12, 22} In these circumstances, wedge or segmental ileal resection may be required to ensure the anastomosis is incorporating healthy intestinal mucosa.

Importantly, this study is the first to report the measured distance between gastric oxyntic cells and ulceration of the intestinal-type mucosa of the Meckel diverticulum. Despite this novelty, several limitations to our study need to be acknowledged. First, this study is a retrospective review of a relatively small sample size from a single institution, thus there may be unidentified factors leading to selection bias towards a specific surgical technique. For the entire cohort, differences in clinical aspects may have affected the decision to perform open versus laparoscopic diverticulectomy, as suggested by the significant increase in post-operative length of hospital stay among children who underwent open resection. These unique clinical factors may have contributed to the differences in outcome more than the technical approach. Importantly, the authors found no clinical differences within the bleeding cohort among those who underwent segmental ileal resection versus diverticulectomy only, as all children with a bleeding Meckel diverticulum were stable and without significant operative risk factors pre-operatively. In this homogeneous population, we surmise that the technical aspect of the two procedures resulted in the observed differences in outcome.

Although the pathologic specimens were re-reviewed and distance between gastric heterotopia and ulcerations formally measured, any distortion of the tissue due to the original processing and orientation of the specimens may have altered these relationships. Moreover, original processing of the specimens for routine H&E staining and histologic analysis of the representative sections may not have captured the ulcerated tissue, as not every millimeter of a Meckel diverticulum is submitted for pathological review. For example, 6 patients in our study who underwent diverticulectomy-only and 2 patients who had segmental ileal resection lacked any evidence of intestinal-type mucosal ulceration or erosion on histology after re-review. Although we favor that the absence of finding ulceration in all specimens was due to a lack of incorporation of the ulcerated mucosa within the representative sections submitted for routine histologic review and diagnosis, we are unable to conclude if the undetected ulcers were simply missed more frequently when diverticulectomy-only was performed or simply were left out of samples submitted for diagnosis. A prospective study with this goal in mind, to examine the entire Meckel specimen circumferentially, would be necessary to clarify that the ulcer is always contained within the diverticulum, which we suspect confidently based upon both the close proximity of the ulcer to the oxyntic cells in the majority of cases and the complete resection of gastric mucosa in all cases. Further, as we did not measure the distance between the ulceration and surgical resection margin, we cannot exclude the possibility that the resection margin incorporated the ulcer, however each slide of every case was re-reviewed by our pathologist for the presence of gastric mucosa, and no histologic abnormality was noted with this re-

analysis. Notably, among the 19 specimens containing a documented ulceration, the ulcer indeed appeared immediately adjacent to the gastric heterotopia, suggesting that the lack of ulceration on other pathologic specimens was likely due to selection of representative areas for histologic processing and evaluation. Regardless, no clinical outcome differences were apparent for those specimens containing an ulcer from those that did not. Appropriate and adequate treatment of a bleeding Meckel diverticulum can be accomplished through complete resection of the heterotopic gastric mucosa, as any residual ulceration should heal in the absence of an acidic environment.¹⁷

5. CONCLUSIONS

In the operative management of children presenting with a bleeding Meckel diverticulum, diverticulectomy-only, when feasible, completely resects gastric heterotopia and likely any adjacent ulceration. Furthermore, operative times and hospitalization are shortened significantly without increasing risk of continued bleeding or other complications.

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Figure 1.

Example of laparoscopic Meckel diverticulectomy. (A) To assess feasibility of diverticulectomy only for bleeding, the base of the Meckel diverticulum can be palpated if via an open approach (not shown) or squeezed gently with an atraumatic bowel grasper as shown to determine its thickness and width. (B) If the base of the diverticulum is of similar thickness as the adjacent ileum, then a stapled resection of the diverticulum only can be performed without compromising luminal diameter. (C, D) Integrity of ileal diameter after diverticulectomy only is shown.

Figure 2.

Histologic analysis of representative Meckel specimens shows the immediate proximity of intestinal mucosal ulceration to acid-producing oxyntic cells of the gastric heterotopia. (A, B) Images of entire sections of two different Meckel specimens are shown. Gastric and intestinal mucosa are labeled. Black arrowhead denotes ulcerated areas. (C, D) Low and high power photomicrograph of same specimen and area of ulceration. Black arrowhead depicts ulcer, which is immediately adjacent to acid-producing gastric mucosa. (E, F)

Example of a different Meckel specimen removed for bleeding that also shows ulcer (black arrowhead) residing immediately adjacent to gastric mucosa.

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Table 1
Demographics and Presenting Characteristics of Children Undergoing Surgical Resection for Meckel Diverticulum

	Bleeding (n = 27)	Obstruction (n = 32)	Diverticulitis or Perforation (n = 18)	Incidental (n = 17)	Other (n = 8)	All (n = 102)
Age, mean years (SD)	7.0 (5.5)	8.3 (6.5)	9.5 (4.7)	3.7 (5.0)	1.8 (0.4)	6.8 (5.9)
Male sex, No. (%)	20 (74%)	27 (84%)	15 (83%)	10 (59%)	2 (40%)	76 (75%)
Race, No. (%)						
White	25 (93%)	29 (91%)	15 (83%)	15 (88%)	8 (100%)	92 (90%)
African American	1 (4%)	1 (3%)	2 (11%)	0 (0%)	0 (0%)	4 (4%)
Asian	0 (0%)	1 (3%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)
Unknown	1 (4%)	1 (3%)	1 (6%)	2 (12%)	0 (0%)	5 (5%)
Ethnicity, No. (%)						
Hispanic	1 (7%)	3 (10%)	0 (0%)	1 (6%)	0 (0%)	6 (6%)
Non-Hispanic	16 (59%)	16 (52%)	15 (83%)	11 (65%)	5 (63%)	63 (62%)
Unknown	9 (33%)	12 (39%)	3 (17%)	5 (29%)	3 (37%)	32 (32%)
Type of surgery, No. (%)						
Open diverticulectomy	5 (18.5%)	12 (37.5%)	2 (11.1%)	14 (82.4%)	7 (87.5%)	40 (40%)
Lap diverticulectomy	11 (40.7%)	9 (28.1%)	10 (55.6%)	0 (0.0%)	0 (0.0%)	30 (29%)
Ileal resection	11 (40.7%)	11 (34.3%)	6 (33.3%)	3 (11.1%)	1 (12.5%)	32 (31%)
Gastric Heterotopia	27 (100%)	13 (41%)	13 (72%)	2 (12%)	3 (60%)	60 (59%)
Pancreatic Heterotopia	3 (11%)	2 (6%)	2 (11%)	0 (0%)	0 (0%)	7 (7%)

Lap: Laparoscopic

Table 2

Characteristics and Clinical Outcomes of Bleeding Meckel Diverticulum Patients by Treatment Group.

	Diverticulectomy (n = 16)	Segmental Ileal Resection (n = 11)	All (n = 27)	P-value
Age, mean years (SD)	7.3 (5.0)	6.5 (6.4)	7.0 (5.5)	0.76
Male sex, No. (%)	12 (75%)	8 (73%)	20 (74%)	1.00
Meckel Scan Positive, No. (%)	14 (87%)	10 (91%)	24 (89%)	1.00
Any Complication	None	None	None	NA
Post-operative Length of Hospital Stay, days (SD)	1.6 (0.9)	4.0 (1.2)	2.6 (1.6)	< 0.001
Gastric Heterotopia	16 (100%)	11 (100%)	27 (100%)	NA
Presence of Ulcer/Erosion, No. (%)	10 (63%)	9 (82%)	19 (70%)	0.41
Distance Between Ulcer and Gastric Heterotopia, mm (SD)	1.0 (2.0)	4.7 (5.4)	2.9 (4.5)	0.07