Open and endoscopic fetal myelomeningocele surgeries display similar in-hospital safety profiles in a large, multi-institutional database

Matthew F. Mikulski, MD, MSHCT; Andrew Well, MD, MPH, MSHCT; Ziv Beckerman, MD; Charles D. Fraser Jr., MD; Michael W. Bebbington, MD, MHSc; Kenneth J. Moise Jr., MD

BACKGROUND: Open intrauterine fetal myelomeningocele repair has demonstrated decreased ventriculoperitoneal shunting and improved motor outcomes despite maternal and fetal risks. Few data directly compare the safety of open vs endoscopic approaches.

OBJECTIVE: This study aimed to analyze in-hospital maternal and fetal outcomes of pregnant patients undergoing open vs endoscopic fetal myelomeningocele repair using a large, multi-center database.

STUDY DESIGN: This was a review of the Pediatric Health Information System database from October 1, 2015, to December 31, 2021. All patients who underwent open or endoscopic fetal myelomeningocele repair according to the International Classification of Diseases, Tenth Revision, were identified. Demographics, gestational age, and outcomes were analyzed. Descriptive and univariate statistics were used.

RESULTS: A total of 378 pregnant patients underwent fetal myelomeningocele repair. The approach was endoscopic in 143 cases (37.8%) and open in 235 cases (62.2%). Overall postprocedural outcomes included no maternal in-hospital mortalities or intensive care unit admissions, a median length of stay of 4 days (interquartile range, 4–5), 14 cases (3.7%) of surgical and postoperative complications, 6 cases (1.6%) of intrauterine infections, 12 cases (3.2%) of obstetrical complications (including preterm premature rupture of membranes), 3 cases (0.8%) of intrauterine fetal demise, and 16 cases (4.2%) of preterm delivery. Compared with an open approach, the endoscopic approach occurred at a later gestational age (25 weeks [interquartile range, 24–25] vs 24 weeks [interquartile range, 24–25]; $P<.001$) and had an increased rate of intrauterine infection (6 [4.2%] cases vs 0 [0%] case; $P=.002$). There was no difference between approaches in the rates of surgical complications, obstetrical complications, intrauterine fetal demise, or preterm deliveries.

CONCLUSION: Compared with an open approach, endoscopic fetal myelomeningocele repair displays a comparable rate of fetal complications, including intrauterine fetal demise and preterm delivery, and a similar in-hospital maternal safety profile despite an association with increased intrauterine infection.

Key words: fetal surgery, maternal outcomes, myelomeningocele repair, surgical approach

Introduction

Intrauterine fetal surgery began in 1981, and the breadth of indications and frequency of fetal surgeries have increased over the past 40 years.[1] Of note, 1 indication is in the antenatal treatment of fetal myelomeningocele (fMMC), a form of spina bifida that results from incomplete neural tube closure. This incomplete closure combined with acquired in utero exposure of the spinal cord leading to further degeneration (the so-called 2-hit hypothesis) can result in several complications, including hydrocephalus, motor dysfunction or paralysis, sensory deficits, bladder and bowel incontinence, and neurocognitive disabilities.[2,3]

With the Management of Meningocele Study (MOMS) trial and full 30-month follow-up of the cohort, open fMMC repair has demonstrated reduced ventriculoperitoneal shunting, fewer instances of hindbrain herniation at delivery, and improved motor outcomes.[3,4] Since then, open fMMC repair has become a standard option to be weighed against maternal risks, such as pulmonary edema, pulmonary emboli, surgical site infections, and combined maternal-fetal risks, such as chorioamniotic membrane separation, placental abruption, preterm premature rupture of membranes (PPROM), intrauterine infections, and preterm delivery (PTD).[3,5–11]

Surgical techniques have advanced from an exclusively open approach used in the MOMS trial to the advent of endoscopic approaches to correct the defect.[3,12–14] The endoscopic approach, if it achieves the same benefits to the fetus as the open approach, may allow for a trial of vaginal labor, may avoid cesarean deliveries in subsequent pregnancies, and may decrease overall morbidity associated with the open approach.[15] Licci et al's[16] systematic review highlighted the fact that most published reports other than the MOMS' trial surrounding fMMC repair are single-center reports, vary substantially in surgical technique, and do not directly compare open vs endoscopic approaches.[7,12,14,16–21] Similarly, other systematic reviews are limited by the number of patients and studies investigated, even when attempting to focus on the surgical approach.[22,23] Lastly, a recent fetoscopic registry reported similar prenatal and postnatal outcomes compared with the MOMS cohort but focused exclusively on the endoscopic method.[24]

With these previous limitations in mind, we sought to study a direct comparison of open vs endoscopic fMMC repair in terms of acute maternal and fetal complications. The goal of this study was to analyze in-hospital maternal and fetal outcomes of pregnant

Cite this article as: Mikulski MF, Well A, Beckerman Z, et al. Open and endoscopic fetal myelomeningocele surgeries display similar in-hospital safety profiles in a large, multi-institutional database. Am J Obstet Gynecol MFM 2023;5:100854.

2589-9333/$36.00

http://dx.doi.org/10.1016/j.ajogmf.2022.100854

AJOG MFM at a Glance

Why was this study conducted?

Open intrauterine fetal myelomeningocele (fMMC) repair has demonstrated decreased ventriculoperitoneal shunting and improved motor outcomes despite maternal and fetal risks, but few data directly compare the safety of open vs newer endoscopic approaches. The Pediatric Health Information System database provides real-world, multi-institutional data.

Key findings

There were 378 pregnant patients who underwent fMMC repair over 6 years: 143 endoscopic cases (37.8%) and 235 open cases (62.2%). Compared with the open approach, the endoscopic approach displayed similar perioperative rates of intrauterine fetal demise and preterm delivery and demonstrated similar in-hospital maternal safety profiles despite increased intrauterine infections.

What does this add to what is known?

Open fetal surgery is the standard treatment option for myelomeningocele repair. An endoscopic approach, if demonstrating similar maternal and fetal benefits, may be an alternative to the standard open approach.

patients undergoing open vs endoscopic fMMC repair using a large, multicenter database through the Pediatric Health Information System (PHIS).

Materials and Methods

The need for approval for this study was waived by the institutional review board at The University of Texas at Austin Dell Medical School (STUDY00001854, approved October 07, 2021).

Data source

This is a retrospective review of the PHIS, an administrative pediatric database operated by the Children's Hospital Association (CHA; Shawnee Mission, Johnson County, KS), a business alliance of children's hospitals. Of note, >45 tertiary pediatric hospitals affiliated with the CHA submit inpatient, emergency department, observation status, and ambulatory surgery data. Data quality and reliability are assured through joint efforts and agreements between participating hospitals and the CHA. Data are deidentified at the time of data submission and are subjected to reliability and validity checks before being included in the database. The PHIS provides an admitting diagnosis, principal diagnosis, and up to 41 additional diagnoses and a principal procedure and up to 41 additional procedures for each episode of care. Records from the fourth quarter of 2015 through the present were coded using the International Classification of Diseases, Tenth Revision (ICD-10).

Study population

Patients having undergone open or endoscopic fMMC repair were identified according to ICD-10 procedure codes (open = 10Q00YE or 10Q00ZE; endoscopic = 10Q03YE, 10Q04YE, 10Q03ZE, 10Q04ZE) from October 01, 2015, to December 31, 2021. Demographics collected included age, reported biological sex, race, ethnicity, and insurance status. Insurance was grouped into private, government (Medicare, Medicaid, Tricare, and other governmental insurance), and other (eg, charity, self-pay, and unknowns). Clinical outcomes provided by the PHIS included disposition (including in-hospital mortality), intensive care unit (ICU) admission, mechanical ventilation, and length of stay (LOS).

Further diagnoses, procedures, and outcomes were identified using ICD-10 codes (Supplemental Table 1). Obstetrical complications were grouped as threatened labor without delivery, PPROM, placental abruption, amniotic sac abnormalities, and uterine rupture. PTD included premature labor with delivery and mechanically induced delivery (ie, cesarean delivery). Perioperative complications were grouped as blood, air, or amniotic pulmonary emboli, pleural effusions, pulmonary edema, hemorrhage, cardiac arrest, cardiomyopathy, temporary mechanical circulatory support or ECMO, mechanical ventilation >96 hours, and acute renal failure. Infectious complications included genitourinary sepsis, intrauterine infections, wound infection, and infection of elements of the genitourinary tract, including endometritis, cervicitis, and vaginitis.

The endoscopic approach is considered a more recently introduced technique than the open approach; therefore, the distribution of procedures was compared between the early half of the study (early; fourth quarter of 2015−2018) and the second half (late; 2019−2021). To account for variation in expertise across hospitals in the cohort, hospitals were considered high volume if ≥50 total cases were performed throughout the study period and low volume if <50 cases.

Statistical analysis

Descriptive statistics were used for demographics, clinical characteristics, and outcomes. Categorical variables are reported as numbers (percentages). LOS is reported as median day (interquartile range [IQR]). The chi-square test and Fisher exact test were used to analyze noncontinuous variables, and the Wilcoxon signed-rank test was used for nonnormally distributed comparisons between groups where appropriate. All statistical tests were 2-tailed, and a P value of <.05 was considered significant. All statistical analyzes were performed using R.[25]

Results

Study population

A total of 378 pregnant patients were identified who underwent fMMC repair (Table 1). Of these patients, 333 (88.1%) were White, 55 (14.6%) were Hispanic, and the mean age at operation was 29.6±5.4 years. An endoscopic approach was used in 143 patients (37.8%), and an open approach was used in 235 patients (62.2%). The procedures occurred at a median

TABLE 1
Baseline patient characteristics

Characteristic	Total	Endoscopic	Open	*P* value
Total	378[a]	143 (37.8)[a]	235 (62.2)[a]	—
Age (y)	29.6±5.4	28.9±5.6	30.0±5.3	.054
White	333 (88.1)	129 (90.2)	204 (86.8)	.322
Ethnicity				
Hispanic	55 (14.6)	29 (20.3)	26 (11.1)	.011[a]
Non-Hispanic	315 (83.3)	109 (76.2)	206 (87.7)	
Unknown	8 (2.1)	5 (3.5)	3 (1.3)	
Insurance				
Private	279 (73.8)	101 (70.6)	178 (75.7)	.106
Government (Medicaid, Tricare, Medicare)	85 (22.5)	33 (23.1)	52 (22.1)	
Other	14 (3.7)	9 (6.3)	5 (2.1)	
Gestational age (wk)	24 (24–25)	25 (24–25)	24 (23–25)	<.001[a]
Year				
Early (2015–2018)	180 (47.6)	60 (42.0)	120 (51.1)	.086
Late (2019–2021)	198 (52.4)	83 (58.0)	115 (48.9)	
Hospital volume				
High volume	333 (88.1)	134 (93.7)	199 (84.7)	.009[a]
Low volume	45 (11.9)	9 (6.3)	36 (15.3)	

Data are presented as number (percentage), mean±standard deviation, or median (interquartile range), unless otherwise indicated.

[a] Denotes statistical significance.

Mikulski. Open vs endoscopic myelomeningocele surgery. Am J Obstet Gynecol MFM 2023.

gestational age of 24 weeks (IQR, 24–25) with the endoscopic approach occurring at a later gestational age than the open approach (25 weeks [IQR, 24–25] vs 24 weeks [IQR, 23–25]; *P*<.001) (Figure 1). There was no conversion from an endoscopic to an open-based procedure after assessing for the presence of both endoscopic and open codes in the same hospital encounter. There was no difference in age, race, or insurance coverage between endoscopic and open approaches. Hispanic patients had greater representation in the endoscopic cohort than in the open approach (29 [20.3%] vs 26 [11.1%]; *P*=.011).

Outcomes

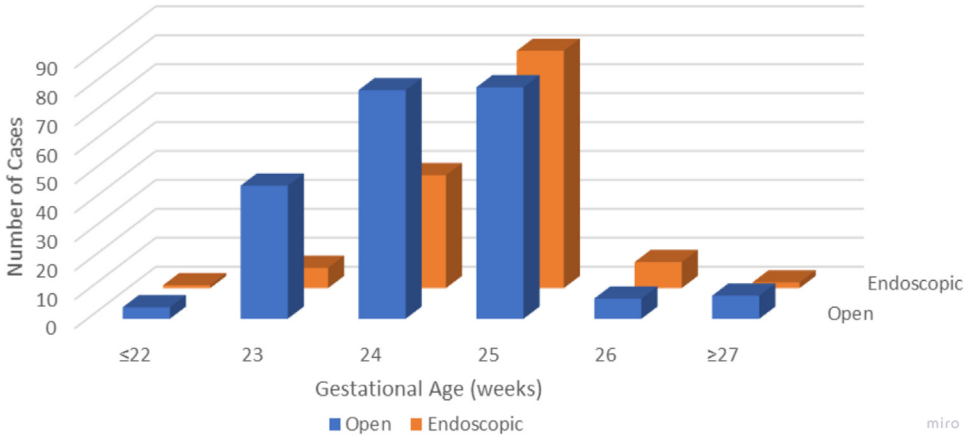
In-hospital outcomes are displayed in Table 2. There was no in-hospital mortality, ICU admission, or patient requiring postoperative mechanical ventilation. The median LOS was 4 days (IQR, 4–5), with the endoscopic approach having a shorter LOS than the open approach (4 days [IQR, 1–5] vs 4 days [IQR, 4–4]; *P*=.019). Overall, there were 12 obstetrical complications (3.2%), 14 perioperative and surgical complications (3.7%), 16 cases (4.2%) of intrauterine fetal demise (IUFD), and 16 PTD (4.2%) with no difference seen between endoscopic and open approaches. In addition, there was no difference between approaches when looking at the individual components of obstetrical complications (PPROM, placental abruption, etc.) or perioperative and surgical complications (amniotic emboli, pleural effusions, etc.). There were 6 intrauterine infections (1.6%) identified, all of which occurred in the endoscopic group (6 [4.2%] vs 0 [0%]; *P*=.002). No other infectious complication was identified.

The 16 episodes of PTD, delivered by surgical removal, occurred at a median of 3 (IQR, 0–7) days postoperatively (Figure 2). Of note, 13 episodes (81.3%) occurred within 7 days of the procedure. The endoscopic and open procedures were similar in terms of time from the fMMC procedure to PTD (median day, 4.5 [IQR, 1.75–7.00] vs 0.5 [IQR, 0.00–7.75], respectively; *P*=.454).

Hospital characteristics

Procedures were reported at 8 hospitals within the PHIS network. These corresponded to various geographic areas nationwide: 3 in the Midwest, 3 in the Northeast, 1 in the West, and 1 in the South. Of note, 3 hospitals were identified as high volume and encompassed 333 cases (88.1%) with 45 cases (11.9%) performed at the remaining 5 hospitals. Moreover, 3 hospitals (37.5%) performed only the open fMMC repair approach, 2 hospitals (25%) reported only the endoscopic approach, and 3 hospitals (37.5%) performed both approaches (Figure 3). Overall, the low-volume hospitals had a lower proportion of endoscopic procedures than open procedures (9 [6.3%] vs 36 [15.3%]; *P*=.009). The 3 high-volume hospitals were the same 3 hospitals that performed both open and endoscopic approaches. When the subpopulation of 333 cases at the high-volume hospitals performing both approaches was analyzed, the previous differences between endoscopic and open approaches identified (LOS and intrauterine infection) remained, and there was no other difference identified (Supplemental Table 2). Similarly, there was no difference in the timing of the procedure in pregnancy, with a consistent median gestational age of 24 weeks (IQR, 24–25) with the endoscopic approach occurring at a later gestational age than the open approach (25 weeks [IQR, 24–25] vs 24 weeks [IQR, 23–25]; *P*<.001). In another subgroup analysis comparing those hospitals performing 1 approach vs those performing both, there was no difference in outcomes (Supplemental Table 3).

FIGURE 1
Endoscopic vs open fetal myelomeningocele repair by gestational age



Mikulski. Open vs endoscopic myelomeningocele surgery. Am J Obstet Gynecol MFM 2023.

Temporal analysis

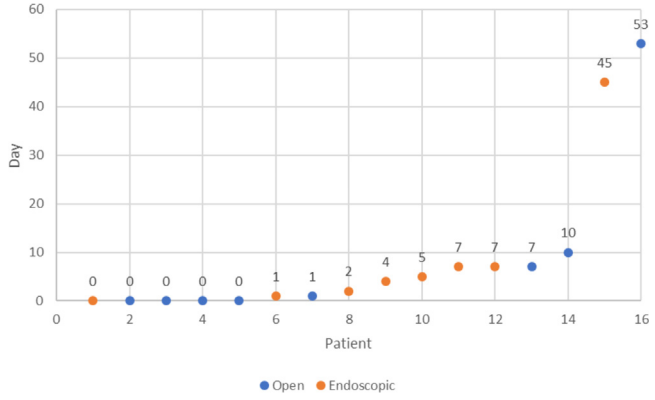
The distribution of cases per year is depicted in Figure 4. There was an increase in the number and percentage of endoscopic procedures from 60 procedures (42%) performed in the early period to 83 procedures (58%) performed in the late period, but this difference did not reach statistical significance (P=.086). To assess for differences in outcome over time, the subgroup analyses of outcomes were performed for early and late periods for each approach (Supplemental Table 4). This revealed no difference for the open approach. The was no difference seen for the endoscopic approach except a longer LOS in the early period than in the late period (median, 4 days [IQR, 1−6] vs 4 days [IQR, 1−4]; P=.005).

Comment

Principal findings

This study sought to compare the in-hospital maternal and fetal outcomes of endoscopic vs open fMMC repair. This study, one of the largest to date investigating fMMC repair (n=378), found no difference between both approaches in the rates of surgical complications, obstetrical complications, IUFD, or PTD. Compared with the open approach, the endoscopic approach occurred at a later gestational age by 1 week and was associated with an increased rate of intrauterine infection (4.2%).

FIGURE 2
Days from myelomeningocele repair to preterm delivery



Mikulski. Open vs endoscopic myelomeningocele surgery. Am J Obstet Gynecol MFM 2023.

Results in the context of what is known

This study included 8 hospitals with most procedures (88.1%) performed at 3 hospitals. A 2014 report describing 59 fetal care centers in the United States reported open fetal surgeries to be possible in just 9 centers.[26] Therefore, the results reported here from 8 institutions are likely in line with trends nationwide, even though some established surgical fetal centers were missed in this cohort. Possibly, the admissions were affiliated with adult hospitals that do not contribute data to the PHIS. In keeping with the increase in the number of fetal care centers nationwide, there was a gradual trend toward an increasing number of cases from 2017 to 2021, although a direct comparison of surgical volume between early and late eras was not statistically different.

The populations were largely similar among institutions and between the 2 surgical approaches. However, although the epidemiology of neural tube defects is complex—combining genetic, geographic, and folate administration differences[27]—the proportion of White patients undergoing fMMC repair in this cohort (88.1%) is higher than the

TABLE 2
In-hospital outcomes of endoscopic vs open fetal myelomeningocele repair

Variable	Total	Endoscopic	Open	*P* value
Total	378	143 (37.8)	235 (62)	—
Length of stay (d)	4 (4–5)	4 (1–5)	4 (4–4)	.019[a]
ICU admission	0 (0)	0 (0)	0 (0)	—
Mechanical ventilation (any)	0 (0)	0 (0)	0 (0)	—
Obstetrical complications	12 (3.2)	7 (4.9)	5 (2.1)	.137
Threatened labor without delivery	2 (0.5)	1 (0.7)	1 (0.4)	.722
Preterm premature rupture of membranes	7 (1.9)	4 (2.8)	3 (1.3)	.288
Placental abruption	4 (1.1)	3 (2.1)	1 (0.4)	.123
Amniotic sac disorder	1 (0.3)	1 (0.7)	0 (0)	.199
Uterine rupture	0 (0)	0 (0)	0 (0)	—
Perioperative and surgical complications	14 (3.7)	5 (3.5)	9 (3.8)	.868
Pulmonary embolism: venous, air, or amniotic	0 (0)	0 (0)	0 (0)	—
Pleural effusion	2 (0.5)	0 (0)	2 (0.9)	.269
Pulmonary edema	7 (1.9)	3 (2.1)	4 (1.7)	.782
Hemorrhage	2 (0.5)	0 (0)	2 (0.9)	.269
Venous system complications	0 (0)	0 (0)	0 (0)	—
Cardiac arrest	1 (0.3)	1 (0.7)	0 (0)	.199
Cardiomyopathy	0 (0)	0 (0)	0 (0)	—
Temporary mechanical circulatory support	0 (0)	0 (0)	0 (0)	—
Extracorporeal membrane oxygenation	0 (0)	0 (0)	0 (0)	—
Mechanical ventilation of >96 h	0 (0)	0 (0)	0 (0)	—
Acute renal failure	2 (0.5)	1 (0.7)	1 (0.4)	.722
Infectious complications	6 (1.6)	6 (4.2)	0 (0)	.002[a]
Sepsis	0 (0)	0 (0)	0 (0)	—
Elements of genitourinary tract infection	0 (0)	0(0)	0 (0)	—
Intrauterine infection	6 (1.6)	6 (4.2)	0 (0)	.002[a]
Wound infection	0 (0)	0 (0)	0 (0)	—
Intrauterine fetal demise	16 (4.2)	8 (5.6)	8 (3.4)	.305
Delivery	16 (4.2)	8 (5.6)	8 (3.4)	.305
Premature labor with delivery	2 (0.5)	1 (0.7)	1 (0.4)	.722
Mechanically induced delivery	16 (4.2)	8 (5.6)	8 (3.4)	.305
Mortality	0 (0)	0 (0)	0 (0)	—

Data are presented as number (percentage) or median (interquartile range), unless otherwise indicated.

[a] Denotes statistical significance.

Mikulski. Open vs endoscopic myelomeningocele surgery. Am J Obstet Gynecol MFM 2023.

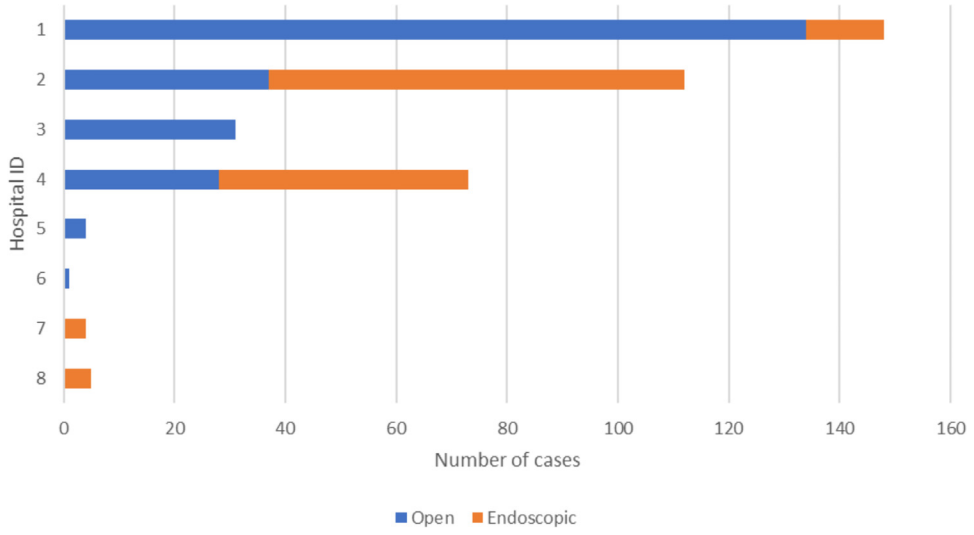
general population (75.8%) of the United States according to the 2020 Census.[28] This suggests that there may be socioeconomic or racial disparities in the baseline access to fMMC repair consistent with previous literature.[29] However, it is encouraging that there was equal access between surgical approaches for different races and insurance statuses.

A difference between approaches included gestational age with the endoscopic approach occurring at a median of 1 week later than the open approach (25 vs 24 weeks). Although these timeframes both still fall within the guidelines of the MOMS trial, the reason for the difference is unclear.[3] It may be provider preference across hospitals that referral for endoscopic repair at specialty centers led to a longer time between diagnosis and intervention or serendipitous that the diagnosis was made later in gestation.

The overall rate of perioperative complications to the mother was very low at 3.7%, with none of the individual complications surpassing 1.9% and no difference demonstrated between the surgical approaches. The absence of any ICU admission, requirement of mechanical ventilation, or in-hospital mortality in this cohort highlighted the continued improvement in outcomes compared with historical reports of fetal surgery.[6,30] The main difference in outcome was a shorter LOS with the endoscopic approach than the open approach (4 days [IQR, 1–5] vs 4 days [IQR, 4–4]; *P*=.019), which is in line with the adoption of a minimally invasive approach seen in a myriad of other procedures.[31–33]

Inherent in the surgical manipulation of the uterus is the risk of IUFD or PTD. Both complications occurred fairly rarely in the immediate perioperative period in this cohort (4.2% each) with no difference between surgical approaches and PTD typically occurring within the first week after the procedure. Other potentially devastating obstetrical complications, such as PPROM (1.9%), placental abruption (1.1%), and uterine rupture (0%), also rarely occurred. These rates of complications are far fewer than those previously reported in the literature,[16] such as PTD occurring in up to 80% of studies, PROM in 67%, and perinatal death in 14% in 1 meta-analysis.[30] However, the rates of complications were consistent across hospitals in this study, mitigating this concern. The discrepancy is likely due to a lack of follow-up data afforded by this database, preventing the capture of complications after the patient is discharged. For example,

FIGURE 3
Surgical approach by hospital



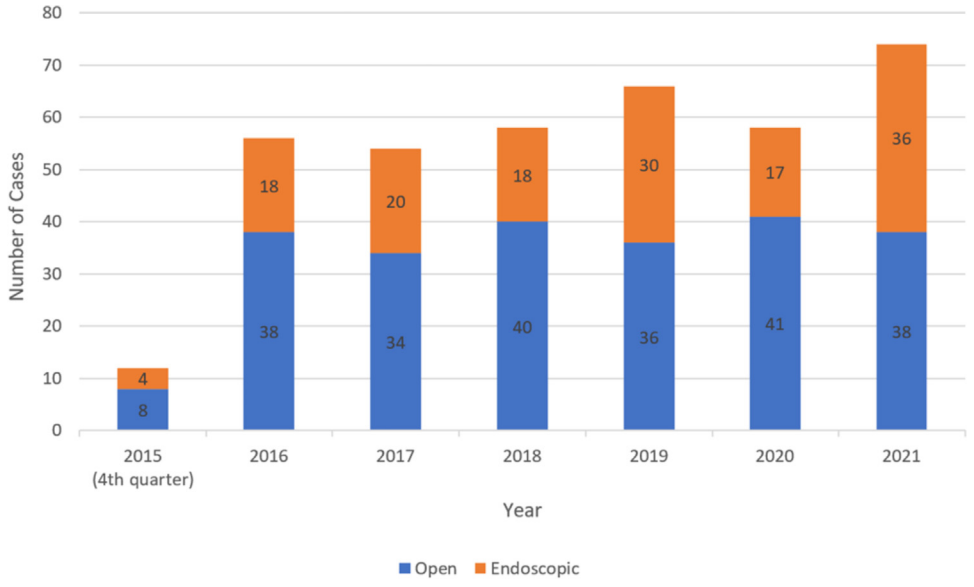
Mikulski. Open vs endoscopic myelomeningocele surgery. Am J Obstet Gynecol MFM 2023.

multiple reports have shown that the average gestational age of PTD after fMMC repair is 34 weeks, much later than the median gestational age at the time of surgery at 24 weeks (IQR, 24–25) in this study.[34,35]

Clinical implications

Regardless of the underlying difference in gestational age at the time of fMMC repair seen in this study, our findings highlighted the need for early diagnosis and treatment to avoid prolonged exposure of the spinal cord in utero, thereby minimizing the exposure described in the "2-hit" hypothesis and maximizing the fetal benefits previously described with open fMMC repair.[2,3] To date, the endoscopic approach has

FIGURE 4
Number of endoscopic vs open fetal myelomeningocele repair cases per year



Mikulski. Open vs endoscopic myelomeningocele surgery. Am J Obstet Gynecol MFM 2023.

shown similar prenatal and postnatal outcomes for the child,[24] but if the endoscopic approach is delayed compared with the open approach, there may be longitudinal outcome differences. Outcomes concerning the timing of fMMC repair should be a target for future studies.

Although it is necessary to be vigilant about the many potential surgical complications possible with fMMC repair, the data presented demonstrated that the in-hospital perioperative risks to the mother are very low. The main difference between approaches was in the prevalence of intrauterine infections, with 4.2% of endoscopic fMMC repair having this infection vs 0% for the open approach (P=.002). This number of cases is low at 6 total patients, but the discrepancy warrants further investigation to determine the underlying cause. Given the longer operative time with endoscopic repair—in 1 meta-analysis demonstrating the endoscopic approach to be 188 minutes and the open approach to be 90 minutes[30]—perhaps additional intraoperative antibiotic administration is necessary, although this study could not investigate perioperative antibiotic management.

Without longitudinal outcomes afforded by this dataset, far-reaching conclusions on fetal-specific risks cannot be ascertained, but the overall acute perioperative risks to the fetus also seem to be low. Overall, these findings can help inform physicians recommending fMMC repair, and pregnant patients undergoing these procedures, of the expected immediate postoperative course and help direct resources for hospitals performing these procedures.

Research implications

This study did not demonstrate increased in-hospital morbidity in mothers and their fetuses undergoing endoscopic fMMC repair, which is a promising finding for the endoscopic approach and its theoretical benefits, such as the potential for a trial of labor and vaginal delivery, but these results require validation. Future studies should directly compare open vs endoscopic approaches in a prospective manner to evaluate the benefits and drawbacks of each approach and investigate longitudinal outcomes. Furthermore, future studies will have to demonstrate similar longitudinal positive postnatal outcomes to support deviating from the fetal repair and maternal approach performed in the MOMS trial.[3]

Strengths and limitations

To the best of our knowledge, this multi-institutional study is one of the largest studies to date investigating fMMC repair (n=378). Moreover, this study described the contemporary results over the preceding 6 years and directly compared the outcomes of endoscopic vs open approaches using real-world data rather than reviews of other published works or using comparisons to the MOMS cohort for the open procedure.[5,16,22–24] In addition, this study is likely representative of the field at large based on the number of institutions and geographic distribution of hospitals.

This study has limitations, mostly corresponding to the retrospective nature of the study and the use of an administrative dataset. Although the open or endoscopic approach can be distinguished using the ICD-10 codes, there is variability in the methodology of the endoscopic approach, such as the use of maternal laparotomy to access the uterus, the number of entry ports used in the hysterotomy, or the type of insufflation used.[12,14,16,19] We were unable to determine these differences. Similarly, we were unable to distinguish the type of closure performed for the spinal defect in either approach. In addition, there may be variability in ICD codes reported among institutions, so other diagnoses, procedures, and complications may be inconsistent across hospitals, although the PHIS has data validation steps to help mitigate this concern. Moreover, there are at least 59 fetal care centers in the nation with >50% of these previously reported to be located at children's hospitals.[26] However, many children's hospitals are associated with an affiliated adult hospital, under whom the admission might be categorized instead of the children's hospital. Therefore, this study may have a selection bias among those hospitals that report data to the PHIS. Lastly, important follow-up information, such as PTD and PPROM, that occur after discharge from the index procedure were not captured as many of the subsequent admissions would be to the adult or maternal hospital and thus not captured by this dataset as previously noted.

Conclusions

Perioperative fMMC repair is safe with low rates of acute in-hospital maternal or fetal complications and low rates of PTD at 4.2%. Compared with the standard open approach, endoscopic fMMC repair displayed comparable in-hospital maternal and fetal safety profiles, despite an association with intrauterine infections (4.2%). Prospective trials directly comparing the approaches should be explored to directly compare their safety profiles. ■

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ajogmf.2022.100854.

References

1. Deprest JA, Flake AW, Gratacos E, et al. The making of fetal surgery. Prenat Diagn 2010;30:653–67.
2. Heffez DS, Aryanpur J, Hutchins GM, Freeman JM. The paralysis associated with myelomeningocele: clinical and experimental data implicating a preventable spinal cord injury. Neurosurgery 1990;26:987–92.
3. Adzick NS, Thom EA, Spong CY, et al. A randomized trial of prenatal versus postnatal repair of myelomeningocele. N Engl J Med 2011;364:993–1004.
4. Farmer DL, Thom EA, Brock JW, et al. The Management of Myelomeningocele Study: full cohort 30-month pediatric outcomes. Am J Obstet Gynecol 2018;218. 256.e1–13.
5. Kabagambe SK, Chen YJ, Vanover MA, Saadai P, Farmer DL. New directions in fetal surgery for myelomeningocele. Childs Nerv Syst 2017;33:1185–90.
6. Golombeck K, Ball RH, Lee H, et al. Maternal morbidity after maternal-fetal surgery. Am J Obstet Gynecol 2006;194:834–9.
7. Winder FM, Vonzun L, Meuli M, et al. Maternal complications following open fetal myelomeningocele repair at the Zurich center for fetal

diagnosis and therapy. Fetal Diagn Ther 2019;46:153–8.
8. Kahr MK, Winder F, Vonzun L, et al. Risk factors for preterm birth following open fetal myelomeningocele repair: results from a prospective cohort. Fetal Diagn Ther 2020;47:15–23.
9. DiFederico EM, Burlingame JM, Kilpatrick SJ, Harrison M, Matthay MA. Pulmonary edema in obstetric patients is rapidly resolved except in the presence of infection or of nitroglycerin tocolysis after open fetal surgery. Am J Obstet Gynecol 1998;179:925–33.
10. Zamora IJ, Ethun CG, Evans LM, et al. Maternal morbidity and reproductive outcomes related to fetal surgery. J Pediatr Surg 2013;48:951–5.
11. Sydorak RM, Hirose S, Sandberg PL, et al. Chorioamniotic membrane separation following fetal surgery. J Perinatol 2002;22:407–10.
12. Pedreira DA, Zanon N, Nishikuni K, et al. Endoscopic surgery for the antenatal treatment of myelomeningocele: the CECAM trial. Am J Obstet Gynecol 2016;214. 111.e1–11.
13. Verbeek RJ, Heep A, Maurits NM, et al. Fetal endoscopic myelomeningocele closure preserves segmental neurological function. Dev Med Child Neurol 2012;54:15–22.
14. Belfort MA, Whitehead WE, Shamshirsaz AA, et al. Fetoscopic open neural tube defect repair: development and refinement of a two-port, carbon dioxide insufflation technique. Obstet Gynecol 2017;129:734–43.
15. Lapa DA. Endoscopic fetal surgery for neural tube defects. Best Pract Res Clin Obstet Gynaecol 2019;58:133–41.
16. Licci M, Guzman R, Soleman J. Maternal and obstetric complications in fetal surgery for prenatal myelomeningocele repair: a systematic review. Neurosurg Focus 2019;47:E11.
17. Bennett KA, Carroll MA, Shannon CN, et al. Reducing perinatal complications and preterm delivery for patients undergoing in utero closure of fetal myelomeningocele: further modifications to the multidisciplinary surgical technique. J Neurosurg Pediatr 2014;14:108–14.
18. Botelho RD, Imada V, Rodrigues da Costa KJ, et al. Fetal myelomeningocele repair through a mini-hysterotomy. Fetal Diagn Ther 2017;42:28–34.
19. Degenhardt J, Schürg R, Winarno A, et al. Percutaneous minimal-access fetoscopic surgery for spina bifida aperta. Part II: maternal management and outcome. Ultrasound Obstet Gynecol 2014;44:525–31.
20. Moldenhauer JS, Adzick NS. Fetal surgery for myelomeningocele: after the Management of Myelomeningocele Study (MOMS). Semin Fetal Neonatal Med 2017;22:360–6.
21. Zamłyński J, Olejek A, Koszutski T, et al. Comparison of prenatal and postnatal treatments of spina bifida in Poland—a non-randomized, single-center study. J Matern Fetal Neonatal Med 2014;27:1409–17.
22. Joyeux L, Engels AC, Russo FM, et al. Fetoscopic versus open repair for spina bifida aperta: a systematic review of outcomes. Fetal Diagn Ther 2016;39:161–71.
23. Kabagambe SK, Jensen GW, Chen YJ, Vanover MA, Farmer DL. Fetal surgery for myelomeningocele: a systematic review and meta-analysis of outcomes in fetoscopic versus open repair. Fetal Diagn Ther 2018;43:161–74.
24. Sanz Cortes M, Chmait RH, Lapa DA, et al. Experience of 300 cases of prenatal fetoscopic open spina bifida repair: report of the International Fetoscopic Neural Tube Defect Repair Consortium. Am J Obstet Gynecol 2021;225.678.e1–11.
25. R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org/. Accessed November 2, 2022.
26. Kett JC, Woodrum DE, Diekema DS. A survey of fetal care centers in the United States. J Neonatal Perinatal Med 2014;7:131–5.
27. Frey L, Hauser WA. Epidemiology of neural tube defects. Epilepsia 2003;44(Suppl3):4–13.
28. United States Census Bureau. QuickFacts: United States. Available at https://www.census.gov/quickfacts/fact/table/US/PST045221. Accessed June 24, 2022.
29. Foy AB, Sawin KJ, Derflinger T, et al. Sociodemographic disparities in fetal surgery for myelomeningocele: a single-center retrospective review. J Neurosurg Pediatr 2021;29:1–5.
30. Araujo Júnior E, Eggink AJ, van den Dobbelsteen J, Martins WP, Oepkes D. Procedure-related complications of open vs endoscopic fetal surgery for treatment of spina bifida in an era of intrauterine myelomeningocele repair: systematic review and meta-analysis. Ultrasound Obstet Gynecol 2016;48:151–60.
31. Lee Y, Fleming FJ, Deeb AP, Gunzler D, Messing S, Monson JR. A laparoscopic approach reduces short-term complications and length of stay following ileocolic resection in Crohn's disease: an analysis of outcomes from the NSQIP database. Colorectal Dis 2012;14:572–7.
32. Stefanou AJ, Reickert CA, Velanovich V, Falvo A, Rubinfeld I. Laparoscopic colectomy significantly decreases length of stay compared with open operation. Surg Endosc 2012;26:144–8.
33. Towfigh S, Chen F, Mason R, Katkhouda N, Chan L, Berne T. Laparoscopic appendectomy significantly reduces length of stay for perforated appendicitis. Surg Endosc 2006;20:495–9.
34. Sacco A, Ushakov F, Thompson D, et al. Fetal surgery for open spina bifida. Obstet Gynaecol 2019;21:271–82.
35. Moldenhauer JS, Soni S, Rintoul NE, et al. Fetal myelomeningocele repair: the post-MOMS experience at the Children's Hospital of Philadelphia. Fetal Diagn Ther 2015;37:235–40.

Author and article information

From the Departments of Surgery and Perioperative Care (Drs Mikulski, Well, Beckerman, and Fraser); Women's Health (Drs Bebbington and Moise), The University of Texas at Austin Dell Medical School, Austin, TX; Department of Surgery, Duke University School of Medicine, Durham NC (Dr Beckerman)..

Received Nov. 28, 2022; accepted Dec. 26, 2022.
The authors report no conflict of interest.
This study received no funding.
The abstract from this study was presented at the American College of Surgeons' Clinical Congress 2022, San Diego, CA, October 18, 2022.

Corresponding author: Matthew F. Mikulski, MD, MSHCT. matthew.mikulski@austin.utexas.edu