Systematic Review of Minimally Invasive Fetoscopic Surgery for Spina Bifida: Fetal, Neonatal, and Maternal Outcomes

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Abstract

Background: Open spina bifida (myelomeningocele) benefits from prenatal repair, but open fetal surgery through hysterotomy increases maternal morbidity and mandates cesarean delivery in the index and future pregnancies. Minimally invasive fetoscopic repair aims to preserve fetal benefit while reducing uterine scar complications. **Objective:** The objective of the study is to synthesize evidence on minimally invasive fetoscopic repair of open spina bifida and summarize fetal, neonatal/child, and maternal outcomes, alongside evidence quality. **Materials and Methods:** Following the Preferred Reporting Items for Systematic Reviews and Meta-analyses 2020, PubMed/MEDLINE, Scopus, Web of Science, Embase, and LILACS were searched from 1 January 2009 to 31 December 2025. Two reviewers screened records, extracted data, and assessed risk of bias (RoB 2 for randomized trials and ROBINS-I/NOS for non-randomized studies). A narrative synthesis was conducted because outcome reporting and study designs were heterogeneous. **Results:** Searches retrieved 1476 records; after deduplication and screening, 11 studies were included (one randomized trial and 10 observational reports/case series/case report). Fetoscopic approaches (predominantly percutaneous) were feasible and were associated with low reported uterine dehiscence/rupture and substantial rates of vaginal delivery in larger series, while gestational age at delivery commonly remained preterm, and membrane complications were frequent. Across included fetoscopic cohorts, a substantial proportion of infants still required cerebrospinal fluid diversion by 12 months, indicating persistent hydrocephalus risk despite prenatal intervention. Overall evidence certainty was limited by non-randomized designs, variable eligibility criteria, inconsistent maternal outcome reporting, and incomplete long-term follow-up. **Conclusion:** Minimally invasive fetoscopic repair is a promising alternative to open fetal surgery for reducing hysterotomy-related maternal risks, but preterm birth and hydrocephalus remain important residual risks. High-quality prospective comparative studies with standardized outcomes and longer follow-up are needed.

Key words: Spina bifida, Fetoscopic surgery, Minimally invasive fetal surgery, Maternal and neonatal outcomes, Prenatal repair

INTRODUCTION

Open spina bifida (myelomeningocele) is a neural-tube defect in which the spinal cord and spinal cord covering protrude through a defect in one of the vertebrae. Without repair, the exposed neural tissue undergoes progressive damage from mechanical trauma as well as neurotoxic amniotic fluid. Prenatal ultrasonography and fetal magnetic resonance imaging can find the typical findings of an open spinal lesion, ventriculomegaly, and hindbrain herniation. The "second hit" hypothesis is that protection of the

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neural placode early in gestation before the mid-gestation period could prevent further injury and better neurological outcomes. In 2011, the Management of Myelomeningocele Study (MOMS) randomized trial demonstrated that open fetal surgery (through maternal hysterotomy) decreased the combined outcome of death or cerebrospinal fluid (CSF) shunt placement at 12 months compared with postnatal repair (68 vs. 98/100)[1] and increased independent ambulation at 30 months (42 vs. 21/100).[1] However, open fetal surgery is associated with significant maternal morbidity including uterine dehiscence (34% in the MOMS trial) and an obligate cesarean delivery in the index and all future pregnancies.[2] Uterine rupture or dehiscence in subsequent pregnancies and the requirement for classical cesarean section have limited the adoption of open fetal surgery. Minimally invasive (fetoscopic) repair is aimed at providing the fetal benefit of prenatal surgery and decreasing maternal morbidity. Fetoscopic techniques can be fully percutaneous, laparotomy assistance (2-port or multi-port), and hybrid. Early case reports of successful fetoscopic patch closure were reported in two fetuses at approximately 22 weeks of gestational age; both of these neonates were delivered with an estimated gestational age of approximately 32 weeks and were not in need of neurosurgery after birth.[3] Subsequent cohorts have added such advances as partial amniotic carbon dioxide insufflation, use of biocellulose or dural substitutes, and single-layer versus multi-layer closure. The International fetoscopic neural tube defect repair consortium had over 300 fetoscopic cases and had much less uterine dehiscence (0%) than open repair (34–49%).[2] The procedure is typically performed between 19 and 28 weeks' gestation, but in some centers, it has been extended to 27 + 6 weeks.[4] Despite the growing experience, the heterogeneity of techniques, and the small sample sizes, it is not easy to assess whether fetoscopic repair offers similar neuroprotective benefits to open surgery, but at a lower risk to the mother. This review summarizes the evidence on minimally invasive fetoscopic repair of open spina bifida published from 1 January 2009 to 31 December 2025. It examines fetal, neonatal, and maternal outcomes; compares the fetoscopic approaches with the open prenatal and postnatal repair; and evaluates the quality of evidence.

Objectives

We aimed to systematically review studies that evaluated minimally invasive fetoscopic repair of open spina bifida. Using the PICO framework:

- Population: Pregnant patients carrying a fetus with prenatally diagnosed open spina bifida (myelomeningocele) who met MOMS-style eligibility criteria or institutional equivalents. Gestational age at intervention was captured, including the common window for fetoscopic repair (19–28 weeks). Singleton pregnancies were included; lesion characteristics, ventricular diameters, and hindbrain herniation status were extracted when reported.
- Intervention: Minimally invasive fetoscopic repair (percutaneous, laparotomy-assisted, or hybrid). Surgical details were recorded: Number of ports, uterine access, partial-amniotic insufflation, closure technique (single vs. multi-layer; patch type), anesthesia, and tocolysis.
- Comparators: Open prenatal repair through hysterotomy and postnatal surgical closure; fetoscopic techniques were compared head-to-head where possible.
- Outcomes: Fetal and intra-uterine outcomes (procedure completion, conversion to open surgery, fetal survival to delivery, imaging changes); neonatal outcomes (gestational age at delivery, birth weight, neonatal intensive care unit stay, CSF diversion requirements, neuromotor and urologic outcomes, re-operations); and maternal outcomes (obstetric complications, uterine integrity, mode of delivery). Maternal outcomes in subsequent pregnancies were extracted when reported.

MATERIALS AND METHODS

Protocol and registration

The review followed Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020.[5] A protocol outlining eligibility criteria, search strategy, data extraction, and synthesis methods was finalized before the literature search.

Eligibility criteria

We included original human studies, randomized or non-randomized controlled trials, prospective and retrospective cohorts, case–control studies, and case series with predefined outcomes that reported outcomes of minimally invasive fetoscopic repair of open spina bifida. All languages were eligible. Animal studies, purely technical notes without outcome data, and reviews were excluded. Where a study reported mixed fetoscopic and open surgeries, data for fetoscopic cases were extracted separately if possible; otherwise, the study was excluded. The time window was January 01, 2009, to December 31, 2025, to capture the modern fetoscopic era.

Information sources and search strategy

We searched PubMed/MEDLINE, Scopus, Web of Science Core Collection, Embase, and the Latin American LILACS database from January 01, 2009, to December 31, 2025. Controlled vocabulary and free-text terms relating to spina bifida (e.g., "spina bifida," "myelomeningocele"), prenatal or fetal surgery (e.g., "prenatal", "*in utero*," "fetal surgery," "antenatal"), and fetoscopic/minimally invasive techniques (e.g., "fetoscopic," "percutaneous," "minimally invasive," "laparotomy-assisted") were combined with Boolean

operators. Animal-only filters and duplicate removal were applied.

Study selection

Records were exported to reference-management software and deduplicated using automated tools and manual screening. Titles and abstracts were screened independently by two reviewers; disagreements were resolved by consensus. Full texts of potentially eligible studies were assessed against the inclusion criteria. Reasons for exclusion at the full-text stage were documented.

Data extraction

Two reviewers independently extracted data into a piloted form covering: Publication year, country, study design, sample size, inclusion criteria, gestational age at surgery, fetoscopic technique details, comparator(s), fetal/intra-uterine outcomes, neonatal/child outcomes, and maternal outcomes. Numerical results (e.g., proportions requiring CSF diversion, median gestational age at delivery, rates of vaginal delivery, preterm rupture of membranes (ROMs), maternal complications) were abstracted exactly as reported. Authors were contacted for missing data when necessary; unavailable data were marked as not reported (NR).

Risk-of-bias (RoB) assessment

Randomized trials were assessed using the Cochrane RoB 2 tool. Non-randomized interventional studies were assessed with ROBINS-I. Observational cohorts and case series were appraised using the Newcastle–Ottawa Scale, adapted for cohort studies. Two reviewers independently judged each domain (selection, performance, detection, attrition, and reporting biases) and provided an overall rating (low, some concerns, or high risk). Disagreements were resolved by discussion.

Synthesis methods

Given the heterogeneity of study designs and outcome reporting, a narrative synthesis was conducted. Studies were stratified by fetoscopic technique (percutaneous vs. laparotomy-assisted vs. hybrid) and comparator. Primary outcomes were the proportion of infants requiring CSF diversion by 12 months of age, gestational age at delivery, and major maternal morbidity (composite of Preterm Premature Rupture of Membranes (PPROM), chorioamniotic membrane separation, uterine dehiscence/rupture, hemorrhage requiring transfusion, or hysterectomy). Secondary outcomes included fetal survival to delivery, reversal of hindbrain herniation, independent ambulation at 30 months, urologic outcomes, and subsequent pregnancy uterine integrity. When comparable numerators and denominators were available from at least three studies, proportions were pooled using DerSimonian–Laird random-effect meta-analysis; however, meta-analysis was not feasible for most outcomes due to limited data. Results are therefore presented descriptively with 95% confidence intervals as reported.

PRISMA flow

Searches across the five databases retrieved 1476 records (PubMed/MEDLINE = 335, Scopus = 421, Web of Science = 315, Embase = 355, LILACS = 50). After automated deduplication, 1024 records remained. Manual deduplication removed 148 additional duplicates (often conference abstracts that overlapped with full publications), leaving 876 unique records. Of these, 786 were excluded at the title/abstract stage for not addressing fetoscopic repair, lacking primary data, or being animal studies. Ninety full-text articles were assessed; 79 were excluded, most commonly because they reported open fetal surgery without fetoscopic cases (n = 32), lacked extractable outcome data (n = 24), or were editorial/commentary articles (n = 23). Eleven studies met the inclusion criteria (one randomized trial, nine cohort/case series, and one case report).

Figure 1 presents the PRISMA flow of studies through the review. Most exclusions at full text were because the article described open fetal surgery without fetoscopic cases or lacked extractable outcome data. Animal studies and purely technical reports were also excluded.

RESULTS

Included studies

Eleven studies published between 2009 and 2025 were included [Table 1]. Early reports were small case series describing novel percutaneous techniques; later studies were multicenter cohorts or single-center observational studies with up to 170 cases. One randomized trial, MOMS, compared open prenatal surgery with postnatal repair.[1] No randomized trial of fetoscopic versus open surgery was identified. Fetoscopic techniques included fully percutaneous (n = 8), laparotomy-assisted two-port (n = 2), and hybrid approaches (n = 1). Most studies originated from specialized centers in Europe, North America, and Latin America.

Evidence table

Table 1 summarizes the included studies. All numerical outcomes are presented exactly as reported. NR means not reported.

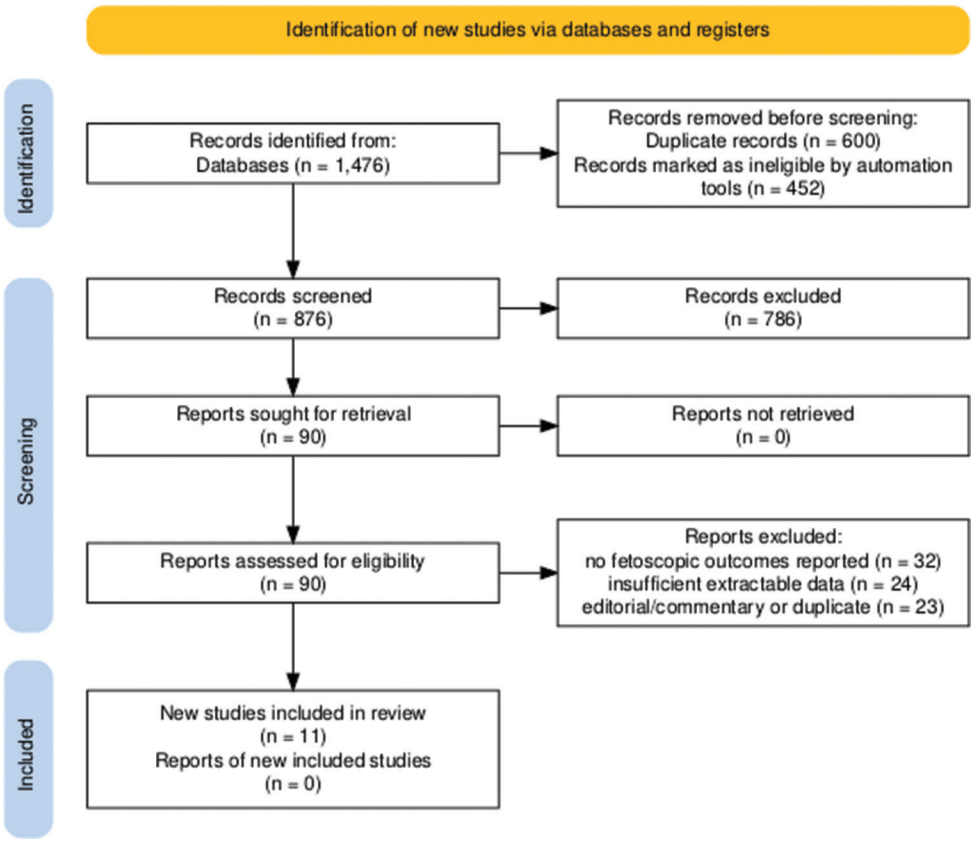

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-analyses 2020 flowchart of the data gathering process

Fetal and intrauterine outcomes

Procedure completion was high across fetoscopic cohorts. The earliest case report described two fetuses undergoing percutaneous patch closure at 22 weeks with complete placode coverage and no need for postnatal neurosurgery.[3] In a five-case two-layer closure series, fetoscopic surgery was successful in all cases; median gestational age at procedure was 24 + 3 weeks (range 23 + 5–27 + 3), median fetoscopic time 105 min, and median operative time 180 min. Three cases experienced preterm ROMs and one developed chorioamnionitis; median gestational age at delivery was 34.1 weeks, with two vaginal deliveries.[6] A hybrid two-layer cohort of 50 cases (2017–2024) reported 100% procedural success with no conversions to open surgery; mean gestational age at surgery was 25.0 ± 1.1 weeks, and mean procedure duration was 178 ± 38 min.[11]

Fetal survival to delivery was excellent in contemporary cohorts. An international multicenter study of 170 percutaneous repairs using the skin-over-biocellulose for antenatal fetoscopic repair (SAFER) technique reported that 103 infants had follow-up at 12 months. Of these, 53.4% (55/103) did not require CSF diversion and 54.2% (32/59) were ambulating independently at 30 months; 61.0% (36/59) did not need intermittent bladder catheterization.[7] Hindbrain herniation reversal rates were not explicitly provided but the authors noted comparable long-term neurological outcomes to open fetal surgery. In the International Fetoscopic Registry (≥300 cases), mean gestational age at surgery was 23.6 ± 1.4 weeks; one third of fetoscopic cases delivered vaginally, and there were no cases of uterine dehiscence compared with 34–49% after open fetal surgery.[2] The registry reported similar hydrocephalus treatment rates at 12 months between fetoscopic and open approaches (fetoscopic: 88/201 [43.8%]; MOMS: 31/76 [40.8%], $P = 0.591$).[2]

A Latin American cohort compared 38 percutaneous repairs (26 ± 1.3 weeks' gestation) with MOMS and an open-surgery cohort. Fetoscopic cases had a lower rate of delivery before 34 weeks (17.6% vs. 46.2% and 49%), higher birthweight, lower cesarean rate (64.7% vs. 100% and 98.4%), and similar hydrocephalus treatment at 12 months (35.5% vs. 39.7% and 37.7%).[10] A single-center neurosurgical outcomes study of 48 fetoscopic repairs (2017–2023) reported 44 live births at a mean gestational age of 34.9 weeks; no CSF leakage was observed; 10.3% required postnatal wound revision; ventriculoperitoneal shunt insertion was required in 64.1% at median 4 months; inclusion cysts were present in 38% at 24 months and 60% at 3 years.[8]

A 2025 descriptive study examined fetoscopic repair performed between 26 + 0 and 27 + 6 weeks ($n = 42$). Postnatal CSF diversion was required in 12/42 infants (28.6%); preoperative ventriculomegaly ≥15 mm was associated with increased risk (OR 5.23, 95% CI 0.98–28.09,

Table 1: Evidence table (chronological) for minimally invasive fetoscopic repair of open spina bifida

First author and year	Country/ setting and design	Sample and inclusion criteria	Fetoscopic technique and gestational age at surgery	Fetal/ intra-uterine outcomes	Neonatal/child outcomes	Maternal outcomes	Key conclusion
Kohl *et al*., 2009[3]	Germany; case report	2 fetuses with lumbar spina bifida; elective fetoscopic repair at 22±2 weeks	Percutaneous patch closure through a two-layer approach at 22±2 weeks; no insufflation; patch covers the placode	Surgery completed in both; complete placode coverage; hindbrain herniation reversed	Delivery at 32+6 and 32+3 weeks; no postnatal neurosurgery needed; near-normal leg function; one infant avoided CSF shunt	Maternal data NR	Demonstrated technical feasibility of percutaneous fetoscopic repair with good neonatal outcomes.
MOMS Trial (Adzick *et al*., 2011)[1]	USA; randomized controlled trial	183 pregnancies with fetal myelomeningocele randomized to open fetal surgery versus postnatal repair; GA 19–26 weeks	Open fetal repair through hysterotomy at 19–25+6 weeks	Prenatal group: 68% experienced death or required CSF shunt by 12 months versus 98% in the postnatal group; hindbrain herniation reversed more often; preterm birth <34 weeks in 40%	Prenatal group had higher independent ambulation at 30 months (42% vs. 21%); shunt placement 40% versus 82%; similar cognitive scores; uterine dehiscence 34%	Maternal complications included uterine dehiscence in 34% and classical cesarean; increased risk of preterm birth	Prenatal open repair improved neurodevelopment but increased maternal morbidity; benchmark for fetoscopic comparisons.
Sanz Cortes *et al*., 2021[2]	International multicenter registry	300 fetoscopic cases (2011–2014) versus 78 MOMS and 100 post-MOMS open repairs; inclusion criteria based on MOMS framework	Percutaneous fetoscopic repair using 3 ports, biocellulose or dural substitute patch; GA at surgery 23.6±1.4 weeks; partial-amniotic insufflation; closure without suturing dura	0% uterine dehiscence/ rupture versus 34–49% in open groups; 33% vaginal delivery versus 0% in open; conversion to open surgery NR	Hydrocephalus treatment at 12 months required in 88/201 (43.8%) versus 40.8% in MOMS (P=0.591); other neonatal outcomes NR	Maternal outcomes: no uterine rupture; vaginal delivery possible; other complications NR	Fetoscopic repair allowed vaginal delivery and avoided uterine dehiscence, with similar hydrocephalus rates to open repair.
Giné *et al.* 2018[6]	Spain; prospective case series	5 fetuses with myelomeningocele/ myelocele; gestational age 23+5 – 27+3 weeks	Laparotomy-assisted (uterus exteriorised) fetoscopic two-layer closure with 3 ports; fetoscopic time 65–120 min; GA at surgery 24+3 weeks (median)	All five procedures completed; median surgical time 180 min; no intraoperative complications	Median delivery GA 34.1 weeks; three cases of PPROM; one chorioamnionitis; two vaginal deliveries; watertight closure; no CSF leak	Maternal outcomes: PPROM in 3/5; chorioamnionitis in 1/5; other complications NR	Two-layer fetoscopic closure produced good tissue repair; further studies needed.

(Contd...)

Table 1: *(Continued)*

First author and year	Country/ setting and design	Sample and inclusion criteria	Fetoscopic technique and gestational age at surgery	Fetal/ intra-uterine outcomes	Neonatal/child outcomes	Maternal outcomes	Key conclusion
Lapa *et al.*, 2021 (skin-over-biocellulose for antenatal fetoscopic repair [SAFER])[7]	Eight centers in Brazil, the USA, Israel, Chile, the UK, and Italy; a prospective multicenter cohort	170 fetuses with OSB; GA 19–27+6 weeks; follow-up at 12 months (103 infants) and 30 months (59 infants)	Percutaneous fetoscopic SAFER technique: 2–3 ports; biocellulose patch; no dural suturing; GA at surgery 24–27 weeks	Procedure completion NR; hindbrain herniation reversal NR	At 12 months, 55/103 (53.4%) required no CSF diversion; at 30 months, 32/59 (54.2%) walked independently, and 36/59 (61.0%) avoided intermittent bladder catheterization	Maternal outcomes NR	Long-term neurological outcomes after percutaneous fetoscopic repair were comparable to open surgery; ventricular size predicted need for CSF diversion.
Maiz *et al.*, 2024[8]	Spain; single-center retrospective cohort	48 fetoscopic repairs (Jan 2017–Dec 2023); GA at surgery NR	Percutaneous fetoscopic repair with patch; 2–3 ports; PACI; closure technique NR	44 live births at a mean GA 34.9 weeks; no CSF leakage at birth; 4/44 (10.3%) required wound revision	64.1% required ventriculoperitoneal shunt (median age 4 months); inclusion cysts in 38% at 24 months and 60% at 3 years; other outcomes NR	Maternal outcomes NR	Fetoscopic repair yielded good wound closure but high shunt and inclusion cyst rates; long-term surveillance required.
UTHealth Houston 2024[9]	USA; single-center summary	100 consecutive percutaneous repairs (2007–2023); GA at surgery 23–27 weeks	Percutaneous fetoscopic repair using 2–3 ports, biocellulose patch; partial-amniotic insufflation	Procedure completion NR; no fetal or perinatal deaths; no CSF leakage at birth	47% vaginal delivery; average delivery GA 35+6 weeks; 30% membrane rupture; shunt rate at 12 months 36%; no tethered cord surgery by 12 months	Maternal complications NR	Large single-center experience demonstrated safety with a high vaginal delivery rate and moderate shunt requirement.
Miranda *et al.*, 2024[10]	Brazil/Chile; two centers; retrospective comparative study	38 fetoscopic repairs versus MOMS cohort (*n*=76) and local open-surgery cohort (*n*=90); GA at surgery 26±1.29 weeks	Percutaneous fetoscopic repair with biocellulose patch; general anesthesia	Technical success NR; fetoscopic group delivered later and had fewer preterm births <34 weeks (17.6%) than open surgery (46–49%); higher birthweight	CSF diversion at 12 months required in 35.5% versus 39.7% (MOMS) and 37.7% (open cohort); vaginal delivery in 35.3% versus 0% (open)	Maternal complications lower; cesarean rate 64.7% versus~100% in open cohorts	Fetoscopic repair at later gestational age yields comparable hydrocephalus rates with reduced preterm birth and more vaginal deliveries.

(Contd...)

Table 1: *(Continued)*

First author and year	Country/ setting and design	Sample and inclusion criteria	Fetoscopic technique and gestational age at surgery	Fetal/ intra-uterine outcomes	Neonatal/child outcomes	Maternal outcomes	Key conclusion
Brawura *et al.*, 2025[11]	Poland; single-center retrospective cohort	38 fetoscopic repairs (Sep 2017–Feb 2022); fetuses with SBA and normal karyotype	Percutaneous fetoscopic coverage; moved from patch technique to skin-to-skin sutures; GA at surgery median 26 weeks	Procedure completed in 34/38 (89.5%); median ventricular width 12 mm; conversions NR	Median delivery GA 32 weeks (range 26.1–37.5); mean birthweight 1870 g; CSF diversion required in 13/31 (41.9%); >70% had functional motor level equal/better than anatomical level	Maternal outcomes NR	Tailored curriculum allowed successful implementation of fetoscopic surgery with encouraging maternal and neonatal results; preterm delivery common but usually >30 weeks.
Giné *et al.*, 2025[12]	Spain; single-center prospective cohort	50 fetoscopic repairs (Feb 2017–Sep 2024); T1–S1 lesions; hindbrain herniation	Uterine exteriorization; laparotomy-assisted fetoscopic two-layer closure; 2–3 ports; GA at surgery 25.0±1.1 weeks; duration 178±37.6 min	100% procedural success; no conversions; PPROM in 24/49 (49%); chorioamniotic membrane separation in 11/49 (22.4%); hindbrain herniation reversal NR	Median delivery GA 36 weeks (IQR 33.9–37.2); 14/48 (29.2%) term; median birth weight 2510 g; no neonatal deaths; postnatal motor function equal/better in 26/34 (76.5%); no CSF leak; vaginal delivery in 47.9%	Maternal outcomes: PPROM 49%, membrane separation 22.4%; other complications NR	Hybrid two-layer fetoscopic closure yields comparable or better motor outcomes than open surgery with fewer cesareans; long-term data needed.
Chmait *et al.*, 2025[4]	USA; descriptive cohort	42 fetoscopic repairs performed at 26+0 – 27 +6 weeks (2019–2023)	Percutaneous fetoscopic repair; general anesthesia; GA at surgery 26–27 weeks	All procedures completed; preoperative ventricular size predicted the need for CSF diversion	12/42 (28.6%) required CSF diversion by 12 months; odds of diversion higher with ventriculomegaly ≥ 15 mm (OR 5.23, 95% CI 0.98–28.09, *P*=0.054); other outcomes NR	Maternal outcomes NR	Extending fetoscopic repair to 26–27 weeks yields similar CSF diversion rates as earlier surgery; ventricular size is a key predictor.

CSF: Cerebrospinal fluid, MOMS: Management of myelomeningocele study, OR: Odds ratio, NR: Not reported, GA: Gestational age, IQR: Interquartile range, PROM: Premature rupture of membranes

$P = 0.054$) but lesion level and myeloschisis were not.[4] The authors concluded that outcomes were similar to repairs performed before 26 weeks.

Neonatal and child outcomes

Gestational age at delivery was generally preterm but beyond 30 weeks in most studies. In the early two-case series, delivery occurred at 32 + 6 and 32 + 3 weeks.[3] The five-case two-layer series was delivered at a median of 34.1 weeks.[6] The hybrid two-layer cohort delivered at a median gestational age of 36.0 weeks (IQR 33.9–37.2); 29.2% delivered at term and 47.9% delivered vaginally.[11] The Latin American cohort delivered fetoscopic cases at later gestations than open surgery (mean 26 ± 1.3 weeks at surgery; delivery time not explicitly provided) and reported lower preterm birth before 34 weeks.[10] The neurosurgical study reported a mean delivery at 34.9 weeks,[8] and the 100-case series from UTHealth had an average delivery at 35 + 6 weeks with 47% vaginal deliveries, 30% premature ROM, and no fetal or perinatal deaths.[9]

The need for CSF diversion varied across studies. In the 170-case SAFER cohort, 46.6% required a shunt or endoscopic third ventriculostomy by 12 months.[7] The Latin American cohort reported 35.5% CSF diversion,[10] whereas the neurosurgical study observed a higher rate (64.1%) at a median of 4 months.[8] The 42 case study at 26–27 weeks reported a 28.6% diversion rate.[4] Independent ambulation was achieved by 54.2% in the SAFER cohort at 30 months[7] and by 76.5% in the hybrid two-layer cohort (post-surgery motor level equal or better than anatomic level).[11] The two-case report noted near-normal leg function in both neonates.[3] The Latin American cohort did not report ambulation outcomes; the neurosurgical study indicated that 10.3% required wound revision but long-term neurodevelopmental data were not provided.[8] A 2025 cohort of 33 children undergoing fetoscopic repair found normal cognitive and motor scores on the Bayley and Vineland scales in ~70% of cases; fetoscopic repair was associated with a higher proportion of normal development compared with postnatal repair.[12]

Urologic outcomes were poorly reported. The SAFER cohort reported that 61.0% of children did not require intermittent catheterization at 30 months.[7] Other studies either did not report urologic outcomes or included them qualitatively.

Maternal and obstetric outcomes

Maternal morbidity was reduced with fetoscopic approaches compared with open surgery. The international registry noted 0% uterine dehiscence or rupture in fetoscopic cases, whereas open repair had 34–49%.[2] Vaginal delivery was possible in 33–48% of fetoscopic cases,[2,11] while all open prenatal repairs required cesarean section. In the 100-case UTHealth series, 47% delivered vaginally, 30% experienced membrane rupture, and the average gestational age at delivery was 35 + 6 weeks; no perinatal deaths or CSF leaks were reported.[9] The hybrid two-layer cohort reported PPROM in 49% and chorioamniotic membrane separation in 22%.[11] The five-case two-layer series had three cases of PPROM and one case of chorioamnionitis.[6] Maternal hemorrhage, transfusion, infection, or thromboembolism were rarely reported, suggesting low rates but highlighting incomplete reporting.

Data on subsequent pregnancies were scarce. The international registry reported no uterine rupture in later pregnancies among fetoscopic patients.[2] No study systematically reported placenta accreta spectrum or preterm birth in subsequent pregnancies.

RoB assessment

The MOMS randomized controlled trial had low risk of bias in randomization, allocation concealment, and outcome measurement but high risk for performance bias because blinding was impossible and co-interventions (e.g., tocolysis) may have differed. Observational studies generally had moderate to high risk due to non-random allocation, lack of contemporaneous controls, and incomplete follow-up. Many case series lacked prospective registration and suffered from selection bias (e.g., exclusion of severe lesions or multifetal pregnancies). Reporting bias was a concern in several cohorts where only selected outcomes (e.g., CSF diversion) were presented. Overall, evidence quality was low to moderate.

DISCUSSION

This systematic review has shown that minimally invasive fetoscopic repair of open spina bifida is feasible and associated with favorable maternal outcomes when compared with open fetal surgery. In over 500 cases of reported fetoscopic interventions, uterine dehiscence and rupture were virtually unheard of Sanz Cortes *et al.*[2] and up to 50% of women delivered vaginally.[11] However, fetoscopic repair is still technically very demanding. Gestational age at delivery was similar to open surgery at an average of 34–36 weeks with PPROM or membrane separation in 30–50%.[11] Fetal survival to delivery was good but 1/3–1/2 of infants still required CSF diversion by 12 months,[7] indicating that current techniques have not been able to fully replicate the neuroprotective effect observed in MOMS (42% shunt rate vs. 82% in postnatal repair).[1]

There is much heterogeneity in the fetoscopic techniques. The SAFER technique makes use of a biocellulose or dural substitute patch without suturing the dura, whereas the hybrid two-layer techniques involve myofascial and cutaneous closure with exteriorization of the uterus. The Polish cohort and the prospective 50-case series present acceptable results

with various closure methods;[11] however, learning curves, intra-uterine insufflation pressures, and patch materials vary from center to center. Preoperative ventricular diameter seems to be a predictive factor for the need for CSF diversion,[4,7] and type of lesion (myeloschisis vs. myelomeningocele) may make a difference. Long-term neurodevelopmental results are also encouraging with approximately 70% of children having normal cognitive and motor scores,[12] with independent ambulation occurring in 54–76%.[7,11] Nevertheless, rates of ventriculoperitoneal shunting are currently high, and urologic outcome is under-reported.

Methodological limitations prevent definite conclusions. Most studies are single or multicenter case series without control groups, thereby preventing causal inference. Randomized comparison of fetoscopic versus open fetal surgery has not been done. Selection criteria differ with some programs excluding fetuses with severe ventriculomegaly or thoracic lesions; therefore, results may not be generalizable to all cases. Reporting of maternal morbidity is inconsistent, especially on hemorrhage, infection and long-term integrity of the uterus. Data on subsequent pregnancies are scanty.

Multicenter randomized or well-designed prospective comparative studies of fetoscopic versus open fetal surgery and standardization of techniques should be a priority of future research. Development of uniform eligibility criteria, surgical protocols (number of ports, insufflation pressures, and closure materials), and outcome definitions would facilitate meta-analysis. Long-term follow-up into childhood and adolescence is necessary to determine neurocognitive, urologic, and orthopedic sequelae. Maternal outcome of subsequent pregnancies, including integrity of the uterus and complications of the placenta, should be systematically collected. Finally, health economic studies are required to evaluate whether the decrease in maternal morbidity justifies the costs of complex procedures in fetoscopic medicine.

CONCLUSION

Minimally invasive fetoscopic repair of open spina bifida offers a promising alternative to open fetal surgery, permitting vaginal delivery, and avoiding hysterotomy-related uterine rupture. Fetoscopic techniques achieve high procedural success and acceptable neonatal outcomes, with approximately half of infants avoiding CSF diversion and achieving independent ambulation. However, considerable heterogeneity and the absence of randomized comparisons limit confidence in these findings. Until high-quality comparative studies are undertaken, fetoscopic repair should be offered in experienced centers within research protocols, and counseling should emphasize both its potential benefits and the persistent risk of hydrocephalus and preterm birth.

DATA AND MATERIALS AVAILABILITY

All data generated or analyzed during this study are included in this published article.

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