A comparison of MRI appearance and surgical detethering rates between intrauterine and postnatal myelomeningocele closures: a single-center pilot matched cohort study

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Abstract

Purpose: Intrauterine myelomeningocele repair (IUMR) and postnatal myelomeningocele repair (PNMR) differ in terms of both setting and surgical technique. A simplified technique in IUMR, in which a dural onlay is used followed by skin closure, has been adopted at our institution. The goal of this study was to compare the rates of clinical tethering in IUMR and PNMR patients, as well as to evaluate the appearance on MRI.

Methods: We conducted a retrospective review of 36 patients with MMC repaired at our institution, with 2:1 PNMR to IUMR matching based on lesion level. A pediatric neuroradiologist blinded to the clinical details reviewed the patients' lumbar spine MRIs for the distance from neural tissue to skin and the presence or absence of a syrinx. An EMR review was then done to evaluate for detethering procedures and need for CSF diversion.

Results: Mean age at MRI was 4.0 years and mean age at last follow-up was 6.1 years, with no significant difference between the PNMR and IUMR groups. There was no significant difference between groups in the distance from neural tissue to skin (PNMR 13.5mm vs IUMR 17.6mm; p=0.5). There was no difference in need for detethering operations between groups (PNMR 12.5% vs IUMR 16.7%; RR 0.75; CI 0.1-5.1).

Conclusions: There was no significant difference between postnatal- and intrauterine-repaired myelomeningocele on MRI or in need for detethering operations. These results imply that a more straightforward and time efficient IUMR closure technique does not lead to an increased rate of tethering when compared to the multilayered PNMR.

Introduction

Despite progress in prevention and intervention, myelomeningocele remains a major source of morbidity and mortality in both developed and developing countries.[1,2] Since the completion of the Management of Myelomeningocele Study (MOMS),[3] intrauterine myelomeningocele repair (IUMR) has become an established option in the management of myelomeningocele across well more than the original three centers.

IUMR and postnatal repair (PNMR) of myelomeningocele differ not only in setting, but also surgical technique. During PNMR, a multilayered closure including dura, myofascia and skin is preferred. This multilayered closure technique has been described for IUMR as well.[4] However, dissecting the tissue-thin dura and performing significant myofascial dissection adds time and damage to the surrounding tissue. At our institution, a small piece of dural substitute is cut to the size of the defect and skin closed primarily in the midline over this graft.[5] The goal is to simplify the procedure in order to effectively close the defect as efficiently and simply as possible. Simplifying IUMR to the simplest technique that maintains the benefits seen in MOMS decreases the operative time needed, which may lower the risks to the exposed fetus and mother. Additionally, it may facilitate the development of less invasive methods of fetal closure.

Few studies have examined the rate of symptomatic tethering in the IUMR population. In the MOMS, surgery for tethered cord was higher in the IUMR group compared to the PNMR group (8% vs. 1%), though this was not statistically significant.[3] These rates are significantly lower than previously reported rates of tethering in myelomeningocele patients, which is 10–30%, likely due to the limited follow-up in the MOMS. More recent studies have indicated that there is no difference in the rates of symptomatic tethering in these two groups.[6,7] It is important to assess the results of different techniques on outcomes to ensure that the benefits of IUMR are being maintained with newer and possibly simpler techniques.

MRI of the lumbar spine demonstrates evidence of tethering in all myelomeningocele patients, making diagnosis reliant on clinical findings.[8–10] However, understanding the differences in appearance of IUMR and PNMR on MRI, specifically the appearance of the tissue superficial to the dural closure, could illuminate the consequences of the different closure techniques, if any exist long term. More simply put, if there is no detectable difference on MRI in terms of the thickness of tissue over the repair site, and no difference in symptomatic tethering, then advocating for simplification of the technique would make sense, and potentially increase its adoption.

To date, no studies have investigated differences in appearance of spinal MRIs in the IUMR and PNMR populations. The goal of this study was to determine differences in the appearance on MRI between IUMR and PNMR populations, as well as the clinical tethering rates.

Methods

A single-institution retrospective review of myelomeningocele patients undergoing operative intervention was performed following Institutional Review Board approval (IRB #111291) at our institution. Inclusion criteria included pediatric patients undergoing myelomeningocele repair with radiographic imaging and follow-up at our institution. The cohort was 2:1 PNMR to IUMR cohort based matched on lesion level.

Closure Technique for IUMR

The exposure of the fetus is done as previously described.[5] After induction of general anesthesia, the mother's abdomen is prepped and draped. The Maternal and Fetal Medicine (MFM) team exposes the uterus and opens it longitudinally. the fetus is positioned with the myelomeningocele exposed in the uterine opening. The placode is released, taking care to not include surrounding dermis or epidermis. If dura is inadequate for closure, as is frequently the case, a piece of dural substitute is placed over the defect and skin closed over this patch. If skin is inadequate for midline closure, releasing incisions are made on the sides to allow midline skin closure and lateral incisions are patched.[11] This technique results in a neurosurgical operative time of approximately 20 minutes, with slightly longer times if releasing incisions needed.

Data Collection

Data collected from the electronic medical record (EMR) included demographics, clinical characteristics (anatomic level of myelomeningocele, clinical evidence of tethered cord, and evidence of urologic, orthopedic, neurologic defects), and age at magnetic resonance imaging (MRI) and last follow-up. Following review of the EMR, spinal MRIs were reviewed by a board-certified neuroradiologist blinded to repair timing. Distance from neural tissue to fascia and neural tissue to skin was measured (Fig. 1). The presence of a syrinx and/or epidermoid or dermoid cyst was also noted. In addition, the neuroradiologist was tasked with predicting timing of repair following review of radiographic evidence. Each patient's EMR were then reviewed for any detethering operations and need for cerebrospinal fluid (CSF) diversion.

The primary outcomes of the study were the appearance of tissue on MRI, measured through distance from neural tissue to fascia and to skin, and incidence of tethering. Secondary outcomes included presence of syrinx and epidermoid or dermoid cysts, as well as need for CSF diversion and diversion type.

Statistical Analysis

Descriptive statistics, including frequency for categorical variables and median and interquartile ranges for continuous variables were performed. Univariate analysis was performed to evaluate differences between the intrauterine repair and postnatal repair cohorts. Chi-square or Fisher's exact tests were used for categorical variables and independent-samples t-test was used for continuous variables. Statistical significance was set *a priori* at p = 0.05. All analysis was performed in IBM SPSS 27.

Results

Demographics

Twelve IUMR patients were randomly chosen from the Maternal Fetal Medicine database. A priori, it was determined that matching would occur on a 2:1 basis. In total, 36 patients with myelomeningoceles (24 PNMR and 12 IUMR) were included in our cohort, the majority of whom were Caucasian (n = 28, 77.8%). Females predominated in both the IUMR (n = 7, 58.3%) and PNMR (n = 15, 62.5%) groups. Compared to the PNMR group, mean gestational age at delivery was two weeks younger in the IUMR group (35.2 ± 2.2 vs. 37.2 ± 1.6 weeks, p = 0.005). This is consistent with previous studies of IUMR.[3,12] There was no statistically significant difference in age of last follow-up between the groups (IUMR 6.6 ± 2.1 vs. PNMR 5.8 ± 2.7 years, p = 0.409) (Table 1**).** Of note, two IUMR patients (16.7%) did require wound revision soon after birth for superficial dehiscence.

Table 1
Demographics and Clinical Characteristics

	Intrauterine Repair (n = 12)	Postnatal Repair (n = 24)	p-value
Sex, n (%)	5 (41.7)	9 (37.5)	0.809
Male	7 (58.3)	15 (62.5)	
Female			
Race, n (%)	11 (91.7)	17 (70.8)	0.672
Caucasian	1 (8.3)	4 (16.7)	
Black/African-American	0 (0)	1 (4.2)	
Hispanic/Latino	0 (0)	1 (4.2)	
Asian/Asian-American	0 (0)	1 (4.2)	
Other			
Gestational Age at Birth (weeks), mean (SD)	35.2 ± 2.2	37.2 ± 1.6	**0.005**
Anatomic Level of Myelomeningocele	0 (0.0)	1 (4.2)	
Thoracic	1 (8.3)	2 (8.3)	
L1-L2	7 (58.3)	12 (50.0)	
L3-L4	3 (25.0)	6 (25.0)	
L5-S1	1 (8.3)	3 (12.5)	
Sacral			
Clinical Evidence of Tethered Cord, n (%)	1 (8.3)	3 (12.5)	0.829
Yes	10 (83.3)	20 (83.3)	
No	1 (8.3)	1 (4.2)	
Indeterminate			
Neurogenic Bladder, n (%)	2 (16.7)	6 (25.0)	0.571
Evidence of Urologic Defect, n (%)	2 (16.7)	0 (0)	**0.040**
Evidence of Orthopedic Defect, n (%)	3 (25.0)	0 (0)	**0.011**
Evidence of Neurologic Defect, n (%)	1 (8.3)	1 (4.2)	0.607
Progressive Scoliosis, n (%)	2 (16.7)	2 (8.3)	0.453

	Intrauterine Repair (n = 12)	Postnatal Repair (n = 24)	p-value
Age at Last Follow-up (years), mean (SD)	6.6 ± 2.1	5.8 ± 2.7	0.409
VPS = ventriculoperitoneal shunt, ETV = endoscopic third ventriculostomy			

Radiographic Characteristics

Mean age at MRI was similar between intrauterine (4.7 ± 1.4 years) and postnatal (3.6 ± 2.7 years) repair groups (p = 0.189). On radiographic analysis, no statistically significant difference was observed in either the mean distance from neural tissue to fascia (6.9 ± 5.4 vs. 4.9 ± 4.7 mm, p = 0.276) or neural tissue to skin (17.7 ± 9.4 vs. 13.5 ± 12.3 mm, p = 0.320) between the IUMR and PNMR groups, respectively. Two patients in both the IUMR (16.7%) and PNMR (8.3%) groups presented with epidermoid cyst (p = 0.941). Both patients in the IUMR group underwent an operation for resection of inclusions cysts, compared to one of the two patients in the PNMR group. Presence of syrinx was noted in 4 intrauterine repair patients (33.3%) and 17 postnatal repair patients (70.8%); these differences did not reach statistical significance (p = 0.092). Table 2 summarizes radiographic characteristics of the two cohorts.

Table 2
Radiographic Characteristics

	Intrauterine Repair (n = 12)	Postnatal Repair (n = 24)	p-value
Age at MRI (years), mean (SD)	4.7 ± 1.4	3.6 ± 2.7	0.189
Neural Tissue to Fascia (mm), mean (SD)	6.9 ± 5.4	4.9 ± 4.7	0.276
Neural Tissue to Skin (mm), mean (SD)	17.7 ± 9.4	13.5 ± 12.3	0.320
Epidermoid, n (%)	2 (16.7)	2 (8.3)	0.941
Dermoid, n (%)	1 (8.3)	0 (0.0)	0.134
Syrinx, n (%)	4 (33.3)	17 (70.8)	0.092

Table 3
Need for Surgical Intervention

	Intrauterine Repair (n = 12)	Postnatal Repair (n = 24)	Relative Risk (95% CI)
Need for Surgical Detethering, n (%)	2 (16.7)	3 (12.5)	0.75 (0.14–3.91)
Need for CSF Diversion, n (%)	7 (58.3)	22 (91.7)	1.57 (0.96–2.57)
	Intrauterine Repair (n = 12)	**Postnatal Repair (n = 24)**	**p-value**
Age at Detethering (years), mean (SD)	2.9 ± 2.4	3.7 ± 3.3	0.795
Age at CSF Diversion (days), median (IQR)	171 (69.5-243.5)	17 (9-55.5)	**0.006**
Type of CSF Diversion, n (%)	2 (28.6)	13 (61.9)	0.126
VPS	5 (71.4)	8 (38.1)	
ETV			

Upon review of spinal MRI by a neuroradiologist blinded to repair timing, the neuroradiologist correctly predicted repair timing based solely off review of radiographic evidence only 38% of the time, indicating that there was not a clear difference on MRI between intrauterine and postnatal closures. Furthermore, the neuroradiologist expressed minimal confidence in predicting repair timing based on MRI, noting that there were not significant qualitative differences in appearance.

CSF Diversion Operations

There were 7 patients (58.3%) in the IUMR group and 22 patients (91.7%) in the PNMR group requiring CSF diversion, a difference that was not significant in our cohort (RR 1.57, 95% CI 0.96–2.57). IUMR patients were significantly older than patients with PNMR at time of CSF diversion (171, IQR 69.5-243.5 vs. 17, IQR 9-55.5 days, p = 0.006).

Tethering

In the IUMR group, 16.7% (n = 2) patients underwent a detethering operation, compared with 12.5% (n = 3) within the PNMR group (RR 0.75, 95% CI 0.14–3.91). In the IUMR group, both patients requiring detethering had worsening of urodynamics and worsening of lower extremity deformity. In the PNMR group, one patient had worsening lower extremity pain and weakness, one patient had progressive scoliosis, and the third patient had a persistent pseudomeningocele and tethered cord was noted at the time of surgical repair. Age at detethering was similar between the cohorts (IUMR 2.9 ± 2.4 vs. PNMR 3.7 ± 3.3 years, p = 0.795). (Table 1).

Discussion

Our study comparing the radiographic appearance of IUMR and PNMR revealed no significant differences in subcutaneous tissue appearance, or other radiographic characteristics, including presence of syrinx and epidermoid or dermoid cysts. Furthermore, the difficulty in which a blinded neuroradiologist was able to predict repair timing further suggested an absence of differences on radiographic imaging between the two groups.

Important outcomes in IUMR closures include rates of CSF diversion and tethering rates. In the current study, there was not a significant difference in rates of CSF diversion between the IUMR and PNMR groups (58.3% vs. 91.7% respectively). The lack of statistical significance may be attributed to the small cohort in this study. The rates were similar to that of the MOMS cohort.[3,13] Consistent with previous literature,[14] patients undergoing IUMR were older and weighed more at the time of CSF diversion compared to PNMR patients.

In this, there was not an increase in tethering rates in the IUMR group (16.7%) patients compared to the PNMR group (12.5%; Table 2). Previous literature has noted that the rates of tethering myelomeningocele patients to be between 10 and 30%.[7,9,10] While a previous study found a rate of tethering in IUMR patients of nearly 33%,[15] a more recent study using the National Spina Bifida Patient Registry demonstrated no difference in the rates of detethering operations between IUMR and PNMR patients (18% vs 16%, respectively), with a mean age at last follow-up of 3.67 years in the IUMR group and 4.08 years in the PNMR group.[6] In our cohort, mean age at last follow-up was 6.6 years in the IUMR group and 5.8 years in the PNMR group. It is possible that additional tethering operations will be necessary for this cohort as they age, based on recent studies demonstrating a risk of tethering of approximately 1.8% per year between ages 0–13,[7] so continued follow-up and ongoing analysis is necessary.

The appearance of the subcutaneous tissue is a novel variable that could help to assess the consequences of different closure techniques. For example, it is possible that not performing a fascial closure could result in less subcutaneous tissue. While the appearance of tethering on MRI is present in nearly all patients following myelomeningocele closure,[8,9] it was important to evaluate the appearance of subcutaneous tissue between the groups to see if the differential closure made a significant difference. There was no difference in the amount of tissue between the skin and neural tissue between the IUMR and PNMR groups. This important in demonstrating that the lack of myofascial flaps does not seem to make a substantial difference in appearance on MRI. The lack of differences is also highlighted by the inability to qualitatively differentiate between IUMR and PNMR on MRI. A board-certified neuroradiologist was only correct 38% of the time when asked to determine if the patient had a IUMR or PNMR accentuating the lack of visible difference between the two groups despite effort to prove otherwise.

There were two IUMR cases (16.7%) that required wound revisions following birth. Neither patient had evidence of CSF leakage or exposure of neural elements, and underwent complex wound closure with plastic surgery. Both of these cases were early in our experience with this technique. Rates of wound

dehiscence in IUMR in the literature have been reported between 0%-13%.[3,14,16] Additionally, as more experience is gained by both surgeon and field, rates of complications have declined.[5]

Other modifications from the technique described in MOMS[3] have been described. Flanders et al.[17] described their results following modification of a technique in which they rotated a myofascial flap over the dural defect and close this layer. The skin is then closed primarily. They report significantly fewer inclusion cysts with this technique compared to their results prior to this modification, as well as lower rates of CSF diversion compared to the MOMS cohort.[17] Notably, they did not include the age at last follow-up, which is important to know as many cysts and symptomatic tethers are not reported until later in life.[7,9,18]

Simplifying the technique while maintaining the benefit of the operation could allow for the further development of less invasive techniques of IUMR. Fetoscopic surgery has recently gained traction with the goal of decreasing morbidity related to an open hysterotomy. A recent analysis of an international registry of centers performing fetoscopic IUMR demonstrated similar rates of hydrocephalus when compared to the MOMS and post-MOMS cohorts.[19] Additionally, 32% of children in the fetoscopic group were delivered vaginally, which is not possible following open hysterotomy. There was increased operative time, and rates of preterm premature rupture of membranes and oligohydramnios were higher in the fetoscopic cohort. This technique does require significant training for neurosurgeons and the entire prenatal surgery team.[20,21] It is also important to note that the Texas Children's group, who has pioneered this technique, recently published that moving away from a simpler closure reduced their postoperative immediate take back for CSF leaks after delivery.[22]

While our study demonstrated no significant differences radiographically or increased tethering rates in prenatal compared to postnatal closure, it is not without limitation. First, the single-institution nature of this study limits the size of the cohort; larger scale studies evaluating different techniques of closure are indicated to more fully understand possible differences in outcomes. Furthermore, the surgery was performed by one team and the radiographic findings in our study were interpreted by a single neuroradiologist. Therefore, subsequent validation of this study should be pursued in order to determine whether the results of this study can be replicated. Despite these limitations, our study is the first to compare intrauterine prenatal closure and postnatal closure of myelomeningocele from a radiographic perspective, showing little difference between the tissue covering the placode between the two operative techniques In addition, there appeared to be no difference in symptomatic tethering rates, bring the opportunity to emphasize the substantial differences in closure techniques that have evolved since MOMS and the idea perhaps that we should begin moving towards adopting the least complex procedure that allows the field to maintain the benefits seen in MOMS and also provides short and longer term protection from returning to the operating room for any reason.

Conclusion

Compared to postnatal closure, intrauterine prenatal repair of myelomeningocele was not associated with different appearance on MRI, less subcutaneous tissue, or increased tethering rates requiring surgical management. Simplifying the procedure and maximizing efficiency may promote adoption of prenatal closure across the field and ultimately in low- and middle-income countries where previously not considered. Additionally, this may facilitate the adoption of less invasive techniques of intrauterine repair in the future as technology and innovation continue to evolve.

Declarations

Ethics approval and consent to participate: Vanderbilt University Medical Center Institutional Review Board (IRB) #111291

Consent for publication: Yes

Availability of data and materials: Available upon reasonable request

Competing interests: None

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Authors' contributions: Data collection was performed by MJC and reviewed by SP and THK. Statistical analysis was performed by MJC And THK. The main manuscript text was prepared by MJC and ART. Conception of the study and study supervision was performed by JCW, KAB, and SAB. All authors reviewed the manuscript.

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References

1. Shaer CM, Chescheir N, Schulkin J. Myelomeningocele: A Review of the Epidemiology, Genetics, Risk Factors for Conception, Prenatal Diagnosis, and Prognosis for Affected Individuals. Obstet Gynecol Surv. 2007;62(7):471–479. doi:10.1097/01.ogx.0000268628.82123.90
2. Sims-Williams HJ, Sims-Williams HP, Kabachelor EM, Fotheringham J, Warf BC. Ten-year survival of Ugandan infants after myelomeningocele closure. J Neurosurg Pediatrics. 2017;19(1):70–76. doi:10.3171/2016.7.peds16296

3. Adzick NS, Thom EA, Spong CY, et al. A randomized trial of prenatal versus postnatal repair of myelomeningocele. New England Journal of Medicine. 2011;364(11):993–1004. doi:10.1056/nejmoa1014379
4. Heuer GG, Adzick NS, Sutton LN. Fetal Myelomeningocele Closure: Technical Considerations. Fetal Diagn Ther. 2015;37(3):166–171. doi:10.1159/000363182
5. Dewan MC, Wellons JC. Fetal surgery for spina bifida: JNSPG 75th Anniversary Invited Review Article. J Neurosurg Pediatrics. 2019;24(2):105–114. doi:10.3171/2019.4.peds18383
6. Worley G, Greenberg RG, Rocque BG, et al. Neurosurgical procedures for children with myelomeningocele after fetal or postnatal surgery: a comparative effectiveness study. Dev Medicine Child Neurology. Published online 2021. doi:10.1111/dmcn.14792
7. Dias MS, Wang M, Rizk EB, et al. Tethered spinal cord among individuals with myelomeningocele: an analysis of the National Spina Bifida Patient Registry. J Neurosurg Pediatrics. Published online 2021:1–7. doi:10.3171/2020.12.peds20868
8. Spoor JKH, Gadjradj PS, Eggink AJ, et al. Contemporary management and outcome of myelomeningocele: the Rotterdam experience. Neurosurg Focus. 2019;47(4):E3. doi:10.3171/2019.7.focus19447
9. Shurtleff D, Duguay S, Duguay G, et al. Epidemiology of Tethered Cord with Meningomyelocele. Eur J Pediatr Surg. 1997;7(S 1):7–11. doi:10.1055/s-2008-1071200
10. Hudgins RJ, Gilreath CL. Tethered spinal cord following repair of myelomeningocele. Neurosurgical focus. 2004;16(2):E7.
11. Wellons JC. Intra-uterine closure of myelomeningocele defects with primary versus bipedicle fasciocutaneous flaps: a single center post-MOMS retrospective cohort study. Presented at: 45th Annual Meeting of the American Society for Pediatric Neurosurgeons; February 3, 2022.
12. 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: Clinical article. J Neurosurg Pediatrics. 2014;14(1):108–114. doi:10.3171/2014.3.peds13266
13. Tulipan N, Wellons JC, Thom EA, et al. Prenatal surgery for myelomeningocele and the need for cerebrospinal fluid shunt placement. Journal of neurosurgery Pediatrics. 2015;16(6):613–620. doi:10.3171/2015.7.peds15336
14. Cools M, Northam W, Goodnight W, Mulvaney G, Elton S, Quinsey C. Thirty-day medical and surgical readmission following prenatal versus postnatal myelomeningocele repair. Neurosurgical focus. 2019;47(4):E14. doi:10.3171/2019.7.focus19355
15. Danzer E, Thomas NH, Thomas A, et al. Long-term neurofunctional outcome, executive functioning, and behavioral adaptive skills following fetal myelomeningocele surgery. Am J Obstet Gynecol. 2016;214(2):269.e
1-269.e8
. doi:10.1016/j.ajog.2015.09.094

16. Moldenhauer JS, Soni S, Rintoul NE, et al. Fetal myelomeningocele repair: the post-MOMS experience at the Children's Hospital of Philadelphia. Fetal diagnosis and therapy. 2015;37(3):235–240. doi:10.1159/000365353
17. Flanders TM, Madsen PJ, Pisapia JM, et al. Improved Postoperative Metrics with Modified Myofascial Closure in Fetal Myelomeningocele Repair. Oper Neurosurg. 2019;18(2):158–165. doi:10.1093/ons/opz115
18. Furtado LMF, Filho JADCV, Dantas F, Sousa CM de. Tethered Cord Syndrome After Myelomeningocele Repair: A Literature Update. Cureus. 2020;12(10):e10949. doi:10.7759/cureus.10949
19. Cortes MS, 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(6):678.e1-678.e11. doi:10.1016/j.ajog.2021.05.044
20. Belfort MA, Whitehead WE, Bednov A, Shamshirsaz AA. Low-Fidelity Simulator for the Standardized Training of Fetoscopic Meningomyelocele Repair. Obstetrics Gynecol. 2018;131(1):125–129. doi:10.1097/aog.0000000000002406
21. Gandy K, Castillo H, Rocque BG, Bradko V, Whitehead W, Castillo J. Neurosurgical training and global health education: systematic review of challenges and benefits of in-country programs in the care of neural tube defects. Neurosurg Focus. 2020;48(3):E14. doi:10.3171/2019.12.focus19448
22. Belfort MA, Whitehead WE, Shamshirsaz AA, et al. Comparison of two fetoscopic open neural tube defect repair techniques: single- vs three-layer closure. Ultrasound Obst Gyn. 2020;56(4):532–540. doi:10.1002/uog.21915
23. Zaganjor I, Sekkarie A, Tsang BL, et al. Describing the Prevalence of Neural Tube Defects Worldwide: A Systematic Literature Review. Plos One. 2016;11(4):e0151586. doi:10.1371/journal.pone.0151586
24. Kessler BA, Catalino MP, Quinsey C, Goodnight W, Elton S. Cost of prenatal versus postnatal myelomeningocele closure for both mother and child at 1 year of life. Neurosurg Focus. 2019;47(4):E15. doi:10.3171/2019.7.focus19417

Figures

Figure 1

Subcutaneous tissue measurements. Distances from neural tissue to fascia (1) and neural tissue to skin (2) were measured by a board-certified neuroradiologist and recorded upon review of spinal MRI.