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Surgical techniques for open fetal repair of myelomeningocele

Nalin Gupta¹

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Abstract The current standard for fetal repair of myelomeningocele is an open exposure of the gravid uterus with control of the amniotic membranes, and then a multi-layer closure of the fetal defect. The nature of the surgical repair has evolved and requires a series of steps that take into account the delicate nature of the fetal tissues. The individual surgical steps are described including potential pitfalls.

Keywords Fetal surgery · Myelomeningocele · Chiari I malformation · Hydrocephalus

Background and rationale for fetal surgery

Fetal surgery arose from a desire to treat severe congenital anomalies such as diaphragmatic hernia, or bladder outlet obstruction that were often fatal, either in utero, or after delivery [1]. Success with these surgical procedures and improved outcomes led to a consideration of other potential less severe conditions, such as myelomeningocele. The initial technical advances were pioneered in animal models, but the focus was to develop strategies that reduced maternal morbidity and the likelihood of preterm delivery.

Although children with myelomeningocele demonstrate a broad range of abnormalities, it is useful to separate the neurologic deficits into two groups: primary and secondary. The primary neurological deficits are those directly caused by the arrested development of the spinal cord [2]. The secondary

neurological deficits include delayed loss of motor function, worsening bowel and bladder control, and scoliosis. These can occur from related events such as hydrocephalus, Chiari II malformation, and tethered spinal cord. The functional neurological level is either at the same level as the vertebral anomaly, or actually higher than the vertebral level, resulting in worse neurological function, in more than 80% of patients with open NTDs [3]. The structure of the spinal cord is substantially disrupted and disorganized leading, but it is unknown if there is a capacity for further development [4]. Indeed, results from the Management of Myelomeningocele Study (MOMS) noted that children who had fetal repair had a better function than expected [5].

Pre-operative evaluation

Most fetuses with myelomeningocele are identified during a mid-gestation ultrasound. The location and associated anomalies can be identified at this time using a combination of the ultrasound findings and MR scans [6]. In the MOMS trial, fetuses with more complex anomalies such as kyphotic angulation were excluded from fetal intervention. This was based on the need to minimize surgical risks which could rise by increased closure time, blood loss, and to reduce the likelihood of a complex structural defect that would either lead to excessive time for closure, or blood loss during the closure. It is not known if more complex anomalies derive benefit from fetal closure as those enrolled.

Although the quality of current imaging is excellent, there are specific features of the lesion that are difficult to know prior to the actual procedure. This includes the presence or size of the CSF-containing sac, whether normal skin extends along the sac, the width of the actual lesion, and size of the

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placode. All of these features affect, to varying degrees, the actual repair.

Anesthetic and maternal considerations

Intra-operative treatment

The anesthetic and maternal requirements for successful fetal surgery are complex and detailed, and these procedures cannot be performed safely without close communication of the entire team [7]. Failure to identify and correct situations that lead to fetal distress can lead to significant difficulties.

A uterine incision can, if not managed properly, lead to strong contractions. Increased tone can lead to placental separation and fetal distress. During the surgical procedure, tocolysis (reduced uterine tone) is achieved by the use of two to three minimum alveolar concentrations (MACs) of volatile anesthetic agent. At the time of hysterotomy closure, the inspired concentrations of halogenated agents are slowly decreased. This regimen facilitates extubation of a fully awake patient and minimizes the likelihood of coughing or straining and jeopardizing the integrity of the uterine closure. Since the reduced amount of anesthetic agent may lead to increased uterine tone, to combat this increase, a loading dose of magnesium sulfate is simultaneously administered intravenously, followed by a continuous infusion. This infusion will continue for at least 24 h post-operatively in an attempt to maintain uterine relaxation and minimize post-operative contractions (see post-operative care below).

Surgical procedure

Equipment and room setup

Thorough planning and communication are required between members of the surgical team. In particular, the room layout should be considered since several sets of equipment are required during the procedure. As well, in addition to the neurosurgical team, there is often a member of the maternal-fetal team present, and an ultrasonographer who is monitoring the fetus during the procedure. At our institution, the fetal repair is performed with the assistance of an operating microscope, which provides magnification of the surgical field and superior lighting. In addition, the transmitted image is clearly visible to other members of the team.

Procedure duration

Including exposure and closure of the uterus, the entire procedure usually lasts between 2 and 3 h. The actual fetal repair can usually be performed between 45 and 75 min. The

duration of the procedure is important since a key objective is to avoid premature delivery either from early labor or from fetal distress. Although there is no specific upper limit with respect to time, the shorter the procedure is, the less likely the fetus will experience physiologic stress. Close coordination between the neurosurgeon and the maternal-fetal team is essential to avoid unnecessary delays during the procedure.

Hysterotomy and exposure

There are several aspects to the exposure that may impact the closure of the actual myelomeningocele. First is the site of the hysterotomy. The location of the placenta, and the orientation of the fetus, will usually determine the exact location of the hysterotomy. If the placenta is located along the posterior uterine wall, then an anterior incision will allow access to the fetus. If the hysterotomy can be placed at the superior dome of the uterus with the mother lying in a neutral, supine position, then the fetus will “float” to the top of the uterus with the neural tube defect framed in the hysterotomy (Fig. 1a). This is the ideal position for the fetus and has a number of advantages: (a) the fetal back is maintained in a flat position which facilitates closure; (b) the size of the hysterotomy is kept to a minimum; and (c) the total volume of amniotic fluid is preserved, which reduces the likelihood of complications such as kinking of the umbilical cord and fetal distress. If the hysterotomy is located along the side of the uterus, then the fetal back will be tilted and performing the repair is more difficult. An eccentric hysterotomy position can be partially corrected by tilting the entire surgical table.

A second problem that can be encountered with fetal positioning is when the long axis of the fetus is turned so that the fetus will tend to twist or rotate out of the field of the hysterotomy. By supporting the uterus with towels or applying gentle pressure to the uterine wall, the fetus can usually be maintained in a stable position. At times, however, an assistant will need to stabilize the fetal back using direct pressure with his/her fingers or with a retractor. In general, direct pressure or manipulation of the fetus should be avoided since this tends to result in fetal distress.

General principles of closure

The steps used during open fetal repair are similar to those of the post-natal procedure [7, 8]. These include (i) identification of the neural placode, (ii) separation of the placode from the surrounding epithelium, (iii) identification and closure of the dura, and (iv) elevation of the surrounding soft tissues and closure of the skin. The major difference between the pre- and post-natal procedures is the tenuous nature of the fetal tissues. The neural placode is extremely fragile and even limited manipulation will lead to loss of tissue integrity. Although the nerve roots are able to withstand some handling, excessive

Fig. 1 **a** A fetal myelomeningocele exposed through a hysterotomy. The placode is oriented in a vertical direction and is surrounded by a moderately sized large CSF-filled sac. The arachnoid over the lateral margins of the sac is extremely thin and translucent. Uterine staples can be seen at the edge of hysterotomy. **b** A fetal myelomeningocele lesion with a larger, oval-shaped neural placode that is relatively flat, and slightly elevated above the back. **c** A fetal myelomeningocele lesion with the neural placode located in the spinal canal and no sac present. The placode is continuous with a transparent layer of pia/arachnoid that is continuous with the skin edge

tension will cause avulsion from the placode. The dura is often insubstantial, transparent when mobilized, and has the characteristics of arachnoid in older children. The fetal skin is able to

handle surgical dissection, but excessive tension leads to tearing.

Mobilization and closure of the placode

The vast majority of open neural tube defects share several features in common, but each defect has individual unique variations (Fig. 1a–c). The anatomy of the components of the fetal defect is often more straightforward than that encountered in the post-natal setting. Invariably, the abnormal derivative of the neural placode is present in the midline extending in the rostral to caudal direction. Usually, the neural groove is seen as a dark line in the middle of the placode (Fig. 1c). The placode has clearly developed further beyond the single cell layer, but the failure to fold and fuse into a tubular structure profoundly affects its function. Since tissue respects the embryological layer from which they arise, the neural placode and epithelium of the surrounding skin, both derived from ectoderm, are physically continuous at the segment where the myelomeningocele is present.

The junction between the placode and the skin is quite variable. Usually, there is a thin, often translucent tissue layer that extends from the lateral edge of the placode to the medial edge of the skin. Its location is important since it represents the initial point of entry for the surgical repair (Fig. 2a). This layer probably represents the primitive pia/arachnoid and should be incised adjacent to the skin. Once it is opened, the subarachnoid space is entered, and if a sac is present, CSF emerges with resulting decompression of the sac. It is useful to leave a margin of the pia/arachnoid attached to the lateral edge of the placode since this allows the surgeon to manipulate the placode without directly holding it. The placode itself is sufficiently fragile that excessive grasping and holding will result in the tissue falling apart. The translucent nature of the pia/arachnoid in the fetal setting also facilitates identification of the nerve roots which emerge from the ventral aspect of the placode but can be displaced in a lateral direction within the sac. In the post-natal setting, it is sometimes difficult to identify the direction of the nerve roots since the tissue of the sac is thicker and opaque.

Once the junction between the placode and the skin is opened, and the nerve roots identified, then following the placode in a circumferential manner allows complete mobilization of it. In the post-natal setting, the epithelium can grow over the pia/arachnoid and sometimes the placode itself. Removing the epithelial components is important since this tissue can presumably result in the formation of intra-spinal epidermoid masses. In the fetal setting, the epithelium rarely extends over the placode but the magnification provided by the operating microscope helps with both identification and removal of this tissue.

Although there is no data that supports closure of the placode, on an empiric basis, the author feels that approximating the pial

Fig. 2 **a** The initial step in the mobilization of the placode is dividing the connection between the edge of the placode and the pia/arachnoid. The forceps are holding the edge of the placode. **b** The placode has been detached and the edges are being rolled toward the midline. **c** The edges of the placode have been approximated with a few 7–0 PDS sutures. The placode has been “tubularized.” **d** The very thin dura was detached from the edge of the dermis and reflected toward the midline and closed with a running suture. **e** In flat lesions with wide skin openings, the skin edges can rarely be closed primarily. In this case, a collagen patch is used to cover the skin defect

surfaces of the placode reduces, but does not eliminate, the adhesions that develop between the placode and the overlying dural repair. Release of a tethered spinal cord in future years will be easier when the cord is only attached in the midline at the position where the placode was closed, rather than a situation where the entire placode is adherent to the overlying dura. Closure of the placode also appears to facilitate dural closure. Usually, several

7–0 sutures are used to bring the pial edge together in the midline (Fig. 2b, c).

Dural repair

The dura that is present along the ventral spinal canal is usually the most intact. It then extends laterally beyond the spinal

canal and is loosely attached to the underlying subcutaneous tissues. The dura is primarily derived from mesoderm, and therefore, it must be continuous with a corresponding mesodermal structure. Once the placode is detached from the skin edge, and the skin edge is elevated upward, the junction of the dura and dermis of the skin can be seen. The junction point is where a small incision is made, after which, gentle instillation of saline into the epidural plane with a small angiocatheter lifts the dura away from the underlying tissues, which minimizes trauma. Between 18 and 20 weeks of gestation, the dura can be very thin and difficult to handle. After 22 weeks of gestation, the dura becomes more substantial and can be handled more easily. Once the dura is circumferentially detached from the dermis and separated from the underlying lumbar fascia, it can be closed using a running 6-0 or 5-0 suture (Fig. 2d). If the amount of dura is insufficient, then a patch is used to close the opening. Typically, if the dural dissection is performed carefully, dural patches are rarely needed. In order to reduce the likelihood of intracellular dermoid cysts, a synthetic collagen matrix is used to create a dural barrier. If the primary dural layer is too thin, then the dural substitute can be sewn directly to the edge of the fascia creating a much more robust layer.

Skin closure

Following dural closure, the fetal skin is closed as a single layer incorporating the superficial and deeper tissues. In general, dissection of the underlying muscle and fascia is not attempted because excessive fetal blood loss should be avoided, and the duration of the procedure minimized. Elevation of the skin and separation from the underlying subcutaneous tissues is relatively straightforward. If the skin defect is small, or if it is narrow, then a primary skin closure can be performed. Pulling on the skin is possible up to a point but it can tear easily. Small openings in the skin caused by handling with forceps or tension from suture points generally close rapidly, although a few interrupted 6-0 sutures can be used to approximate the edges. If a primary closure is achieved, the final post-natal appearance is often excellent. For situations where insufficient skin is available to close the lesion, either skin flaps, relaxing incisions, or acellular dermis can be used as a patch (Fig. 2e). In order to reduce the complexity of the closure, we do not perform skin flaps for fetal repair, and relaxing incisions are no longer used because of the resulting scars are disfiguring.

Post-natal considerations

In general, the management of an infant who has undergone fetal repair is the same as those delivered at full term. A neurologic evaluation and assessment by other teams such as

Fig. 3 A newborn who had a primary repair of his fetal myelomeningocele defect. There is a small hemangioma along the healed incision, and the skin suture is visible, but otherwise, the appearance of the back is excellent

urology, orthopedics, and pediatrics is performed. In order to decide if CSF shunting is required, ventricular size at birth should be determined so that it can be followed during the initial hospitalization and after discharge.

In the lumbar region, the fetal repair usually appears well healed, and even if there are small deficiencies in the skin, they usually cover quickly (Fig. 3). Although a secondary repair of the skin may be necessary after delivery, this has rarely been necessary. In situations where a dural patch was used during the fetal repair, the patch itself is often visible but surrounded by granulation tissue at the time of delivery (Fig. 4). For reasons that are unclear, the patch itself does not epithelialize in utero. However, during the first 2 weeks after delivery, granulation tissue quickly covers the patch and further closure is rarely required. If there is leakage of CSF, or

Fig. 4 A newborn who underwent fetal repair with a skin patch. The patch is clearly visible, but the edges of the skin have started to epithelialize over the patch

separation of the patch, then a post-natal skin repair may be required; an event that has only occurred once in the author's experience. Removal of the patch and closure of the skin are far easier in the post-natal period since the skin is much stronger, and the size of the defect is smaller relative to the size of the back.

Conclusion

The MOMS trial and pre-trial experience demonstrated that fetal surgery for myelomeningocele can be performed safely with acceptable maternal and fetal risks. The technical steps for reliable fetal closure are well defined and are derived from many years of experience at a number of institutions. It should also be noted that open fetal repair is the option that has been rigorously tested, but other newer options such as endoscopic repair may ultimately supplant this procedure.

Compliance with ethical standards

Conflict of interest None.

References

1. Harrison MR (2000) Surgically correctable fetal disease. *Am J Surg* 180:335–342
2. Copp AJ, Greene ND, Murdoch JN (2003) The genetic basis of mammalian neurulation. *Nat Rev Genet* 4:784–793
3. Rintoul NE, Sutton LN, Hubbard AM, Cohen B, Melchionni J, Pasquariello PS, Adzick NS (2002) A new look at myelomeningoceles: functional level, vertebral level, shunting, and the implications for fetal intervention. *Pediatrics* 109:409–413
4. Hutchins GM, Meuli M, Meuli-Simmen C, Jordan MA, Heffez DS, Blakemore KJ (1996) Acquired spinal cord injury in human fetuses with myelomeningocele. *Pediatr Pathol Lab Med* 16:701–712
5. Adzick NS, Thom EA, Spong CY, Brock JW 3rd, Burrows PK, Johnson MP, Howell LJ, Farrell JA, Dabrowiak ME, Sutton LN, Gupta N, Tulipan NB, D'Alton ME, Farmer DL (2011) A randomized trial of prenatal versus postnatal repair of myelomeningocele. *N Engl J Med* 364:993–1004
6. Patel TR, Bannister CM, Thorne J (2003) A study of prenatal ultrasound and postnatal magnetic imaging in the diagnosis of central nervous system abnormalities. *Eur J Pediatr Surg* 13(Suppl 1):S18–S22
7. Gupta N, Farrell JA, Fau-Rand L, Rand L, Fau-Cauldwell CB, Cauldwell CB, Fau-Farmer D, Farmer D (2012) Open fetal surgery for myelomeningocele. *J Neurosurg Pediatr* 9:265–273. doi:10.3171/2011.3.112.PEDS11403
8. Heuer GG, Adzick NS, Fau-Sutton LN, Sutton LN (2015) Fetal myelomeningocele closure: technical considerations. *Fetal Diagn Ther* 37:166–171. doi:10.1159/000363182