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Editorial

Fetal neurosurgery: A breakthrough in prenatal care

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A R T I C L E I N F O

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1. Introduction

Fetal neurosurgery is a pioneering and rapidly evolving field that involves performing surgery on the fetus while still in the mother's womb. This advanced technique, which is largely focused on correcting neurological defects before birth, offers a new avenue of hope for families facing the daunting diagnosis of fetal anomalies. It is a delicate, high-risk procedure that requires the collaboration of a multi-disciplinary team, including neurosurgeons, obstetricians, anesthesiologists, and neonatologists. Despite its challenges, fetal neurosurgery has made significant strides in improving outcomes for certain conditions, most notably spina bifida.[1,2]

The field represents the intersection of neurology, surgery, and maternal-fetal medicine, addressing conditions that, if left untreated, could result in lifelong disabilities or death. In this article, we will explore the history, techniques, and conditions treated by fetal neurosurgery, as well as the ethical considerations, risks, and future directions of the field.[3–5]

2. Historical Background

Fetal surgery, though a relatively new field, has its roots in the late 20th century. The first successful fetal surgery was performed in the early 1980s by Dr. Michael Harrison, a pioneer in the field. His work laid the foundation for what would become a revolutionary approach to treating life-threatening congenital anomalies before birth. Since then, the field has expanded dramatically, with neurosurgical procedures being among the most significant advancements.[5,6]

The first reported fetal surgery for myelomeningocele (MMC) was performed in 1994 at Vanderbilt University by a multi-disciplinary team led by Noel Tulipan and Joseph Brunner.[4] The procedure was performed endoscopically with carbon dioxide insufflation using fibrin glue and a maternal split-thickness skin graft to cover the neural placode. This report was the head-water of a stream of clinical research that crested in a randomized controlled trial comparing fetal MMC repair with postnatal repair.

Neurosurgical interventions, such as the prenatal repair of myelomeningocele (the most severe form of spina bifida), have evolved from experimental procedures to accepted treatments in specialized centers. The development of improved imaging techniques, advancements in surgical tools, and a better understanding of fetal development have all contributed to the growth of fetal neurosurgery.

3. Key Conditions Treated by Fetal Neurosurgery

Fetal neurosurgery is primarily used to address a handful of congenital anomalies that can significantly impair neurological function if left untreated. The most common

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conditions include:

3.1. Spina bifida (Myelomeningocele)

Spina bifida is one of the most well-known conditions treated through fetal neurosurgery. It occurs when the neural tube, which forms the spinal cord, fails to close properly during early pregnancy, leaving part of the spinal cord exposed. This can lead to a range of severe complications, including paralysis, hydrocephalus, and bladder and bowel dysfunction.

Traditionally, spina bifida is repaired after birth, but studies have shown that prenatal repair significantly improves outcomes. The landmark Management of Myelomeningocele Study (MOMS), published in 2011, demonstrated that fetal surgery reduces the need for ventriculoperitoneal shunting and improves motor function compared to postnatal surgery.[1,2]

In MOMS, fetal surgery was performed between 19 and 25 weeks' gestational age. Currently, most operations are performed after 23 weeks of gestational age, in General and epidural anesthesia, followed by laparotomy and hysterotomy. The hysterotomy is 6 to 8 cm, allows access to the MMC lesion.[7–9]

3.2. Hydrocephalus

Hydrocephalus, characterized by an abnormal accumulation of cerebrospinal fluid within the brain's ventricles, can cause increased intracranial pressure, leading to brain damage. In severe cases diagnosed during pregnancy, fetal neurosurgery may involve inserting a shunt to drain excess fluid before birth. This can help prevent further neurological damage and improve cognitive outcomes.[3]

3.3. Encephaloceles

An encephalocele is a rare condition where brain tissue protrudes through a defect in the skull. While some cases are mild and can be managed after birth, severe encephaloceles may require intervention in utero to prevent further damage to the brain and surrounding tissues. Fetal neurosurgery may help reduce the size of the encephalocele and improve the likelihood of normal brain development.

3.4. Intraventricular Hemorrhage (IVH)

IVH occurs when there is bleeding into the brain's ventricular system, which can lead to brain damage, particularly in premature infants. In cases where IVH is detected in utero, neurosurgical interventions may be considered to mitigate the damage and improve neonatal outcomes.

4. Surgical Techniques

Fetal neurosurgery requires a highly specialized skill set and precise techniques to minimize the risks to both the mother and the fetus. The two primary approaches are open fetal surgery and minimally invasive fetoscopic surgery.

For the neurosurgeon, the goals of fetal surgery are to stop the CSF leak and protect the neural elements from amniotic fluid and trauma as the fetus moves within the uterus. These goals are best achieved with a multilayered watertight closure.[1–3]

4.1. Open fetal surgery

In open fetal surgery, an incision is made in the mother's abdomen and uterus to access the fetus.

The hysterotomy is 6 to 8 cm, avoids the placenta,and allows access to the MMC lesion.[9] The fetus is partially exposed, allows necessary repair, such as closing the spinal defect in spina bifida. This method allows for direct visualization and manipulation of the fetal structures, offering a high degree of precision.

However, open fetal surgery carries significant risks, including premature labor, infection, and the potential for uterine rupture in future pregnancies. Mothers who undergo this procedure often require a caesarean section for both the current and any subsequent deliveries.

Pedroso et al., suggest that operating through a mini-hysterotomy (2.0–3.5 cm) increases the average gestational age, lowers the prematurity rate, and results in a lower incidence of uterine dehiscence.[10]

4.2. Fetoscopic surgery

Fetoscopic surgery is a minimally invasive technique that uses small incisions and specialized instruments, including a camera, to perform the procedure. Unlike open surgery, the uterus is not fully opened, reducing the risk of preterm labor and uterine complications. However, the limited visibility and working space make fetoscopic surgery technically challenging and may not be suitable for all conditions.

Fetoscopic repair avoids the morbidity associated with hysterotomy and allows for a vaginal delivery.

Fetoscopic techniques are still under development for neurosurgical applications, but they hold promise for reducing maternal risks while maintaining the benefits of early fetal intervention.

5. Risks and Complications

Fetal neurosurgery, though life-saving in many cases, is not without its risks. The potential complications can affect both the mother and the fetus.

6. Maternal Risks

For the mother, risks include infection, blood loss, and complications related to anesthesia. There is also the risk of uterine rupture in future pregnancies, especially following open fetal surgery. Premature labor is a common complication, which can lead to preterm birth and its associated risks.

7. Fetal Risks

For the fetus, the risks include injury during the surgery, premature birth, and, in rare cases, fetal death. Preterm birth is particularly concerning, as it can lead to complications such as respiratory distress syndrome, feeding difficulties, and developmental delays. However, the potential benefits of the surgery, especially for conditions like spina bifida, often outweigh these risks when performed in experienced centers.

8. Ethical Considerations

Fetal neurosurgery raises several ethical issues, primarily because the patient is a fetus, which cannot consent to the procedure. Parents must make decisions on behalf of their unborn child, often with limited time and incomplete information. This can create significant emotional and psychological stress.

Informed consent is crucial, and parents need to understand the potential risks and benefits of the surgery, as well as the possible long-term outcomes. It is also essential to consider the potential impact on the mother, who may face complications during and after pregnancy because of the surgery.

The question of fetal rights versus maternal rights is another ethical dilemma. In some cases, the mother may face significant health risks from the surgery, raising the question of whether it is appropriate to prioritize the fetus's health over the mother's well-being.

9. Advances in Imaging and Diagnostics

The success of fetal neurosurgery is heavily dependent on accurate prenatal diagnosis and detailed imaging. Advances in ultrasound technology, magnetic resonance imaging (MRI), and three-dimensional imaging have made it possible to diagnose fetal conditions with greater accuracy and at earlier stages of pregnancy.

MRI has become a valuable tool for assessing the severity of conditions like spina bifida and hydrocephalus. It provides detailed images of the fetal brain and spinal cord, allowing surgeons to plan their interventions more precisely. In the future, improvements in imaging technology may enable even earlier detection and intervention for a broader range of neurological conditions.

10. Long-Term Outcomes and Follow-Up

The long-term outcomes for children who undergo fetal neurosurgery vary depending on the condition being treated and the success of the procedure. For spina bifida, studies have shown that children who receive prenatal surgery are more likely to walk independently, have better bladder and bowel control, and require fewer shunt placements for hydrocephalus than those who undergo postnatal surgery.

MOMS trial showed a significant increase in independent ambulation in the fetal surgery group compared with the postnatal surgery group (44.8% versus 23.9%, P = .004). This was objectively defined as taking 10 steps independently without devices. The fetal surgery group also performed better on the psychomotor development index of the Bayley Scale of Infant Development (BSID), and the Peabody Developmental Motor Scales. Parent-reported mobility and self-care, as measured by the Functional Independence Measure for Children (WeeFIM), were also significantly better in the fetal surgery group. These findings occurred despite a higher rate of prematurity in the fetal surgery group. There were no significant differences in cognitive scores between the two groups.[1]

However, long-term follow-up is essential, as many children will still require ongoing medical care, including physical therapy, neurosurgical interventions, and management of secondary conditions. The psychological impact on both the child and the family is also a critical area of focus for future research.

11. Future Directions

The future of fetal neurosurgery is promising, with ongoing research aimed at refining techniques, reducing risks, and expanding the range of treatable conditions. Advances in stem cell therapy, gene editing, and tissue engineering hold the potential to further improve outcomes for fetuses with neurological conditions.

Stem cell therapy is being explored as a potential adjunct to fetal surgery for conditions like spina bifida. By injecting stem cells into the damaged spinal cord, researchers hope to promote regeneration and improve neurological function after surgery.

Additionally, non-invasive techniques such as focused ultrasound and nanoparticle-mediated therapies are being investigated as potential alternatives to traditional surgery. These methods could offer a less risky option for treating certain fetal neurological conditions in the future.

12. Conclusion

Fetal neurosurgery represents a significant advancement in the treatment of congenital neurological conditions. While the field is still evolving, it has already demonstrated its potential to improve outcomes for conditions like spina bifida and hydrocephalus. The risks associated with the surgery are considerable, but for many families, the potential benefits outweigh these challenges.

As technology and surgical techniques continue to advance, the scope of fetal neurosurgery will likely expand, offering hope to even more families facing the diagnosis of severe fetal anomalies. However, ethical considerations, maternal risks, and the need for long-term follow-up will remain critical components of this complex and evolving field.

13. Source of Funding

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14. Conflict of Interest

None.

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