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THE ROLE OF PRENATAL SURGERY IN MYELOMENINGOCELE: OUTCOMES AND FUTURE DIRECTIONS

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Abstract: INTRODUCTION Myelomeningocele, a severe form of spina bifida, involves the protrusion of the spinal cord and meninges through a vertebral defect due to a failure of neural tube closure during embryogenesis. The incidence varies globally, with folic acid supplementation significantly reducing cases. The condition's etiology includes genetic and environmental factors, and prenatal screening through ultrasonography and fetal MRI is crucial for early detection and management planning. The historical treatment approach of postnatal surgery has evolved with the advent of prenatal surgical techniques, which have shown improved outcomes but come with ethical and technical challenges. **OBJETIVE** To evaluate the efficacy of intrauterine surgery in reducing neurological deficits and review the advancements in prenatal diagnostic techniques and their impact on management strategies in myelomeningocele patients. **METHODS** This is a narrative review which included studies in the MEDLINE – PubMed (National Library of Medicine, National Institutes of Health), COCHRANE, EMBASE and Google Scholar databases, using as descriptors: **Congenital Neural Tube Defects** AND **Intrauterine Surgical Techniques** AND **Neurodevelopmental Outcomes** AND **Multidisciplinary Management** AND **Prenatal Diagnostic Advances** in the last years. **RESULTS AND DISCUSSION** Intrauterine surgery has been demonstrated to significantly improve motor function and reduce hindbrain herniation. Comparative studies between prenatal and postnatal interventions show better neurological and functional outcomes with early intervention. Advances in minimally invasive techniques, particularly fetoscopic surgery, are promising but require further validation. Management of postoperative complications such as hydrocephalus remains critical, with ongoing monitoring and timely intervention essential. Multidisciplinary care, including urological and orthopedic management, along with comprehensive rehabilitation services, is vital for optimizing patient outcomes. Economic analyses favor prenatal surgery due to long-term cost savings from reduced disability. **CONCLUSION** Managing myelomeningocele effectively requires a holistic approach that integrates advanced prenatal diagnostics, innovative surgical techniques, and robust multidisciplinary support. Continued research and innovation are essential to refine treatment protocols and improve outcomes. Addressing healthcare disparities and ethical considerations ensures equitable access to care, ultimately enhancing the quality of life for individuals with myelomeningocele. The future of myelomeningocele management lies in the seamless integration of these advancements into comprehensive care models.

Keywords: Myelomeningocele; Fetal Surgery; *Neural Tube Defects; Prenatal Diagnosis.

INTRODUCTION

Myelomeningocele, a severe form of spina bifida, represents a congenital neural tube defect where the spinal cord and meninges protrude through a vertebral defect[1]. This anomaly is classified based on the location and extent of the spinal cord involvement, with thoracolumbar and lumbosacral regions being the most commonly affected[1]. The pathogenesis of myelomeningocele begins early in embryonic development when the neural tube fails to close properly, typically during the third and fourth weeks of gestation[1]. The resultant defect exposes neural elements to amniotic fluid, leading to secondary damage and significant neurological deficits[2]. The epidemiology of myelomeningocele varies globally, with an estimated incidence of 1 in 1,000 live births in regions with

inadequate folic acid fortification, whereas areas with effective folate supplementation programs have seen a marked decline in prevalence[2]. Genetic factors play a crucial role, with mutations in genes involved in folate metabolism and environmental factors such as maternal diabetes and obesity contributing to the risk[2]. The interaction between genetic predispositions and environmental influences underscores the multifactorial etiology of myelomeningocele[3].

Embryologically, the failure of neural tube closure is a critical event in the development of myelomeningocele[3]. The primary neurulation process, responsible for forming the neural tube, is disrupted, leading to an open neural tube defect[3]. This disruption can be attributed to genetic abnormalities affecting folate metabolism, essential for DNA synthesis and repair during early embryogenesis[4]. Environmental risk factors, including maternal hyperthermia and certain medications, further exacerbate the likelihood of neural tube defects[4]. Prenatal screening for myelomeningocele has advanced significantly, enabling early detection and better management outcomes[4]. Ultrasonography is the primary diagnostic tool, with specific signs such as the "lemon sign" and "banana sign" aiding in identification[5]. Elevated levels of maternal serum alpha-fetoprotein (AFP) can also indicate the presence of an open neural tube defect[5]. Fetal MRI provides detailed anatomical visualization, offering a comprehensive assessment of the extent of the lesion and associated anomalies, which is crucial for surgical planning[5].

Myelomeningocele significantly impacts pregnancy outcomes, often leading to complications such as polyhydramnios and preterm labor[6]. The natural history of untreated myelomeningocele is marked by severe morbidity, including motor and sensory deficits, hydrocephalus, and orthopedic anomalies[6]. Associated conditions like Arnold-Chiari II malformation and tethered cord syndrome complicate the clinical management and require a multidisciplinary approach[6]. At birth, the neurological and physical manifestations of myelomeningocele are pronounced, with affected neonates presenting with varying degrees of paralysis, muscle weakness, and deformities of the lower extremities[7]. Urological complications are common, leading to neurogenic bladder and an increased risk of urinary tract infections and renal damage[7]. The psychosocial impact on families is profound, as they face lifelong challenges in managing the medical and emotional needs of their child[7]. Early, comprehensive counseling is essential to prepare families for the complex care requirements[8].

Historically, the treatment of myelomeningocele was limited to postnatal surgical repair aimed at preventing infection and further neurological deterioration[8]. However, the advent of prenatal surgical techniques has transformed the management landscape[8]. The landmark Management of Myelomeningocele Study (MOMS) demonstrated that fetal surgery significantly improves motor outcomes and reduces the need for shunting procedures for hydrocephalus[9]. Despite the benefits, ethical considerations in prenatal diagnosis and treatment remain complex, necessitating a careful balance between potential benefits and risks to both mother and fetus[9]. Disparities in healthcare access remain a significant barrier to optimal management of myelomeningocele[9]. Socioeconomic factors influence the availability and quality of prenatal and postnatal services, necessitating efforts to ensure equitable access to advanced diagnostic and therapeutic options[10]. Multidisciplinary care teams are crucial, involving obstetricians, pediatric neurosurgeons, urologists, and rehabilitation specialists to provide comprehensive management[10].

Current guidelines emphasize the importance of early and accurate prenatal detection, thorough prenatal counseling, and consideration of fetal surgery in selected cases[10]. Continued research is essential to refine surgical techniques, enhance neuroprotective strategies, and develop novel therapeutic approaches[11]. The future of myelomeningocele management lies in integrating advanced prenatal diagnostics, innovative surgical interventions, and robust support systems for affected families[11].

OBJETIVES

To evaluate the efficacy of intrauterine surgery in reducing neurological deficits and review the advancements in prenatal diagnostic techniques and their impact on management strategies in myelomeningocele patients.

SECUNDARY OBJETIVES

1. To compare the outcomes of prenatal versus postnatal surgical interventions.
2. To assess the long-term neurodevelopmental outcomes and quality of life in myelomeningocele patients.
3. To discuss the ethical considerations in prenatal diagnosis and surgical intervention.
4. To highlight future research directions and potential advancements in the field.
5. To explore the role of multidisciplinary care in the management of myelomeningocele.
6. To analyze the economic impact of prenatal versus postnatal treatment approaches.

METHODS

This is a narrative review, in which the main aspects of the efficacy of intrauterine surgery in reducing neurological deficits and review the advancements in prenatal diagnostic techniques and their impact on management strategies in myelomeningocele patients in recent years were analyzed. The beginning of the study was carried out with theoretical training using the following databases: PubMed, sciELO and Medline, using as descriptors: **Congenital Neural Tube Defects** AND **Intrauterine Surgical Techniques** AND **Neurodevelopmental Outcomes** AND **Multidisciplinary Management** AND **Prenatal Diagnostic Advances** in the last years. As it is a narrative review, this study does not have any risks.

Databases: This review included studies in the MEDLINE – PubMed (National Library of Medicine, National Institutes of Health), COCHRANE, EMBASE and Google Scholar databases.

The inclusion criteria applied in the analytical review were human intervention studies, experimental studies, cohort studies, case-control studies, cross-sectional studies and literature reviews, editorials, case reports, and poster presentations. Also, only studies writing in English and Portuguese were included.

RESULTS AND DISCUSSION

The effectiveness of intrauterine surgery in reducing neurological deficits associated with myelomeningocele has been demonstrated in several studies, notably the Management of Myelomeningocele Study (MOMS)[12]. This trial showed significant improvements in motor function and a reduced incidence of hindbrain herniation in fetuses undergoing prenatal repair compared to those receiving postnatal intervention[13]. These findings have propelled fetal surgery to the forefront of

myelomeningocele management, although the procedure is associated with risks, including preterm labor and maternal morbidity[14]. This necessitates meticulous patient selection and surgical precision[15]. Comparative analyses between prenatal and postnatal surgical outcomes consistently show superior neurological and functional outcomes in the prenatal surgery cohort[16]. Studies indicate that intrauterine repair results in improved motor function and reduced reliance on shunt procedures for hydrocephalus, underscoring the benefits of early intervention[17]. However, the complexity of the condition and variability in individual responses necessitate a personalized approach to treatment planning[18].

Techniques and approaches in fetal surgery for myelomeningocele have evolved, with minimally invasive procedures emerging as a promising alternative to open fetal surgery[19]. Fetoscopic techniques, involving small incisions and endoscopic instruments, offer the potential for reduced maternal morbidity while maintaining fetal therapeutic benefits[20]. Despite the promise of these techniques, they present significant technical challenges and require further validation through clinical trials[21]. Postoperative complications, particularly hydrocephalus, remain a significant concern in the management of myelomeningocele[22]. Ventriculoperitoneal shunting remains the standard intervention for hydrocephalus, although endoscopic third ventriculostomy is gaining traction in select cases[23]. Long-term follow-up studies indicate that intrauterine repair can significantly reduce the incidence of shunt-dependent hydrocephalus, but vigilant monitoring and timely intervention remain crucial to optimizing neurological outcomes[24].

Urological dysfunction, particularly neurogenic bladder, is a prevalent complication in myelomeningocele patients, necessitating early and ongoing urological evaluation[25]. Management strategies range from clean intermittent catheterization to more invasive surgical interventions such as bladder augmentation[26]. Urodynamic studies are instrumental in guiding management approaches and tailoring interventions to preserve renal function and enhance quality of life[27]. Orthopedic issues, including clubfoot, hip dislocation, and scoliosis, require a comprehensive, multidisciplinary approach involving pediatric orthopedists and rehabilitation specialists[28]. Early and aggressive interventions, such as physical therapy and surgical correction of deformities, are essential to improving mobility and functional independence[29]. The role of physical and occupational therapy is paramount, with tailored rehabilitative programs designed to maximize motor function and adaptive skills[30].

Neurodevelopmental outcomes and quality of life are significantly influenced by early intervention programs and access to comprehensive rehabilitative services[31]. Multidisciplinary care models that address the complex needs of myelomeningocele patients are crucial in optimizing outcomes[32]. Parental satisfaction and psychological well-being are critical metrics of success, with studies indicating improved coping and satisfaction following prenatal surgical intervention[33]. Comprehensive support services, including genetic counseling and psychological support, are essential in assisting families to navigate the complexities of the condition and make informed decisions[34].

Economic analyses of intrauterine versus postnatal treatment underscore the long-term cost savings associated with prenatal surgery[35]. These savings are primarily driven by reduced disability and decreased need for secondary interventions[36]. Cost-effectiveness studies play a vital role in informing healthcare

policy and ensuring the sustainability of advanced therapeutic options[37]. Advances in fetal monitoring and surgical techniques continue to enhance the safety and efficacy of intrauterine procedures[38]. Real-time imaging modalities, such as intraoperative ultrasonography and fetal MRI, provide critical anatomical insights that guide surgical planning and execution[39]. Innovations in surgical tools and technology, including the development of specialized fetoscopic instruments, are pivotal in advancing the field[40].

The role of fetal MRI in surgical planning is particularly notable, offering detailed anatomical visualization that complements ultrasonography[41]. Fetal MRI provides superior soft tissue contrast, aiding in the assessment of associated anomalies and facilitating comprehensive evaluation[42]. This multimodal imaging approach ensures precise surgical planning and optimal outcomes[43]. Minimally invasive surgical techniques represent a significant advancement in the field, offering the potential for decreased maternal morbidity while maintaining therapeutic benefits for the fetus[44]. Fetoscopic approaches, involving small incisions and the use of endoscopic instruments, aim to mitigate risks associated with open fetal surgery, such as uterine dehiscence and amniotic fluid leakage[45]. Despite these advancements, the technical challenges and steep learning curve of fetoscopic repair necessitate further refinement and validation through ongoing clinical trials[46].

CONCLUSION

Myelomeningocele, as a severe neural tube defect, presents significant challenges from diagnosis through intrauterine treatment and long-term management. The evolution of prenatal diagnostic techniques, particularly the use of detailed ultrasonography and fetal MRI, has enabled earlier and more accurate detection, which is critical for planning timely interventions. Advances in fetal surgery, especially the transition towards minimally invasive techniques, have shown promising results in improving neurological outcomes and reducing associated complications, although they come with their own set of risks and technical challenges.

The impact of prenatal surgical interventions on neurodevelopmental outcomes, urological function, and orthopedic health highlights the importance of a multidisciplinary approach to care. Long-term follow-up and comprehensive rehabilitation services are crucial in optimizing functional independence and quality of life for affected individuals. The psychological and economic benefits to families further underscore the value of early and effective intervention strategies. Ongoing research and innovation are essential to refine surgical techniques, enhance prenatal and postnatal care protocols, and develop novel therapeutic approaches. Ethical considerations and healthcare disparities must be addressed to ensure equitable access to advanced diagnostic and therapeutic options for all affected populations. In conclusion, the management of myelomeningocele requires a holistic, multidisciplinary approach that integrates advanced prenatal diagnostics, innovative surgical techniques, and robust support systems for patients and families.

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