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LITERATURE REVIEW ON ATRIAL SEPTAL DEFECTS: EMBRYOLOGY, GENETICS, TYPES, AND CLINICAL MANAGEMENT

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Abstract:

Atrial septal defects (ASDs) are among the most common congenital heart defects, characterized by abnormal communications between the atria. This literature review synthesizes current knowledge on embryology, genetics, types, incidence, natural history, associated features, pathophysiology, diagnostics, and management of ASDs, drawing from a comprehensive document on the subject. The review highlights the complex interplay of genetic and environmental factors in ASD development, the diverse morphological presentations, and the evolving treatment strategies, including catheter-based and surgical interventions. Advances in minimally invasive techniques and their implications for pediatric and adult populations are also discussed.

Keywords: Atrial septal defects, Embryology, Interatrial Septum, Congenital Heart Disease

Introduction

Atrial septal defects (ASDs) represent a significant proportion of congenital heart diseases, accounting for 10–15% of defects in children and 20–40% in adults [1]. This review examines the embryological origins, genetic predispositions, morphological classifications, clinical implications, and management strategies for ASDs, emphasizing recent advancements in diagnostic and therapeutic approaches.

Embryology of Atrial Septal Defects

The formation of the interatrial septum begins in the fourth week of gestation with the development of the septum primum and septum secundum [2]. The septum primum emerges from the roof of the common atrium, partially closing the ostium primum. Subsequently, resorption in the septum primum forms the ostium secundum, while the septum secundum develops to create the foramen ovale, allowing right-to-left shunting in utero. Postnatally, increased left atrial pressure typically closes the foramen ovale, but defects in this process result in persistent interatrial communications, such as patent foramen ovale (PFO) or secundum ASDs. Abnormal pulmonary vein connections, particularly partial anomalous pulmonary venous connections (PAPVC), may also arise from improper sinus venosus integration [3].

Genetics of Atrial Septal Defects

Familial recurrence of ASDs is well-documented, with a recurrence risk of approximately 7% for isolated secundum ASDs [4,5,6]. Genetic syndromes associated with ASDs include VACTERL, Trisomy 21, Noonan syndrome, DiGeorge syndrome, and Ellis–Van Creveld syndrome [7]. These conditions often present with extracardiac manifestations, complicating clinical management. Environmental factors, such as maternal exposure to alcohol, hydantoin, valproic acid, or infections like cytomegalovirus, also increase ASD risk [8].

Types of Atrial Septal Defects

ASDs are classified into five main types based on morphology and location:

1. **Patent Foramen Ovale (PFO)**: Results from failure of septum primum and secundum fusion, leading to potential trans-septal shunting [9].
2. **Secundum ASD**: Occurs within the fossa ovalis, varying from slit-like defects to large fenestrated communications [10].
3. **Primum ASD**: Associated with atrioventricular septal defects due to persistent ostium primum [11].
4. **Sinus Venosus Defect**: Linked with PAPVC, typically involving right upper pulmonary veins draining into the superior vena cava [3].
5. **Coronary Sinus ASD**: Arises from unroofing of the coronary sinus, creating an interatrial communication [12].

Incidence and Natural History

PFO is highly prevalent, identifiable in over 60% of healthy infants, with spontaneous closure rates of 87–96% within the first year [9,13]. Secundum ASDs occur in 1.6 per 1000 live births, with a female predominance [1]. Spontaneous closure is common for smaller defects (4–5 mm), but defects larger than 8 mm tend to enlarge over time [14]. Unrepaired ASDs in adults are associated with reduced life expectancy, pulmonary hypertension, and right ventricular dysfunction, particularly after age 40 [15,16].

Associated Features and Pathophysiology

ASDs are often asymptomatic in childhood but may present with late complications such as atrial fibrillation, pulmonary hypertension, and reduced exercise capacity [17]. Associated cardiac anomalies include PAPVC, ventricular septal defects (VSDs), and pulmonary stenosis [18]. Left-to-right shunting increases right ventricular volume overload, leading to dilation and hypertrophy, which may impair both ventricles over time [19]. Pulmonary hypertension is rare in childhood but affects 35–50% of adults with unrepaired ASDs by age 40 [20].

Diagnostic Approaches

Echocardiography, particularly transthoracic with color Doppler, is the gold standard for ASD diagnosis, offering high sensitivity for detecting shunts [21]. Cardiac MRI and CT are valuable for complex cases, such as sinus venosus defects or PAPVC [12]. Electrocardiography often reveals right ventricular hypertrophy and incomplete right bundle branch block, though these findings are less diagnostic in adults [22].

Management Strategies

Indications for Closure

ASD closure is recommended for defects with a pulmonary-to-systemic flow ratio (Qp:Qs) ≥ 1.5:1 or evidence of right ventricular volume overload [23]. Early closure (ages 2–5 years) optimizes outcomes, with survival approaching that of the general population [24]. Contraindications include severe pulmonary hypertension or left ventricular failure [25].

Catheter-Based Closure

Since the first catheter-based closure in 1976, devices like the Amplatzer and Helex occluders have become standard, with success rates of 80–95.7% [26,27]. Complications, occurring in 1.4% of cases, include device embolization and cardiac tamponade [28]. Device closure is less invasive, with shorter hospital stays compared to surgery [29].

Surgical Closure

Surgical options include conventional median sternotomy and minimally invasive approaches like partial sternotomy, mini-thoracotomy, video-assisted thoracoscopic surgery (VATS), and robotically assisted surgery [30,31]. Minimally invasive techniques reduce trauma, improve cosmetic outcomes, and shorten recovery time, particularly in young children [32]. Complications include arrhythmias and residual shunts, with late outcomes influenced by age at repair [24].

Discussion

The management of ASDs has evolved significantly, with catheter-based closures offering a less invasive alternative to surgery for suitable defects. Minimally invasive surgical techniques have improved outcomes in pediatric populations, though challenges remain for complex defects like sinus venosus ASDs. Genetic and environmental risk factors underscore the need for early screening and intervention. Future research should focus on optimizing device designs, refining minimally invasive approaches, and understanding the long-term impacts of ASD closure in diverse populations.

Conclusion

ASDs are complex congenital defects with significant clinical implications if left untreated. Advances in diagnostic imaging and therapeutic interventions have improved outcomes, particularly when closure is performed early. Continued innovation in catheter-based and minimally invasive surgical techniques promises to further enhance patient care, emphasizing the importance of tailored management strategies based on defect type and patient characteristics.

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