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Partial Heart Transplantation: A Narrative Review of a Novel Valve Replacement Strategy

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ABSTRACT

Partial heart transplantation (PHT) is a new surgical option in pediatric cardiac reconstruction that could address major drawbacks of traditional valve replacement. Unlike mechanical or bioprosthetic valves and homografts, the living valve grafts used in PHT can grow with the child. This may help prevent patient–prosthesis mismatch and reduce the need for repeated surgeries as children grow. This review covers PHT from concept to clinical application. It discusses the limitations of current valve replacement methods, the technical success of PHT in preclinical studies, and early clinical outcomes. The review also examines recent advances in graft preservation, immunomodulation, 3D modeling, and tissue engineering that could expand the use of PHT. While PHT is still experimental and experience is limited, it shows promise as a growth-accommodating option for some pediatric patients. Background: Current methods for replacing heart valves have important drawbacks. Prosthetic valves and homografts cannot grow with the pediatric patient, leading to multiple surgeries. PHT is a new approach that uses living grafts with valves that can grow and adapt. Objective: This review examines why and how PHT is applied in practice, its benefits and challenges, and the future perspectives. Methods: Sources include experimental studies, clinical case reports, review articles, and meta-analyses on partial heart transplantation, transplantation immunology, graft preservation, and new tissue engineering methods.

Keywords: heart transplantation; partial heart transplantation; congenital heart disease; heart valve transplantation; valve replacement; graft preservation; transplant immunology

1. INTRODUCTION

Heart transplantation and surgical repair of congenital heart defects have evolved greatly over the past decades. Initially, treatment relied on palliative surgical procedures, followed by increasingly advanced reconstructive and transplant techniques (Holst et al., 2017). As this progress continued, innovative methods for valve replacement surgery were also introduced. These include mechanical valves, bioprostheses, and homografts. However, these approaches were associated with multiple complications — such as thrombosis, immune reactions, structural

deterioration, calcification, and infection (Crago et al., 2023) and the need for later reoperations, since traditional implants do not accommodate patient growth.

In response to these challenges, researchers explored the introduction of a growth-accommodating device that could correct anatomical malformations and adapt to tissue growth in children. Nevertheless, most of these devices had several limitations, and no clinical approaches had yet been established (Feins et al., 2017; Nguyen et al., 2023). Partial heart transplantation (PHT) is a novel surgical approach proposed to address this problem. It is a transplant of living cardiac tissue with a valve that can grow with the pediatric patient (Rajab, 2020).

This review examines partial heart transplantation as a therapy for pediatric valve disease. It focuses on the development and clinical application of PHT, as well as its future directions.

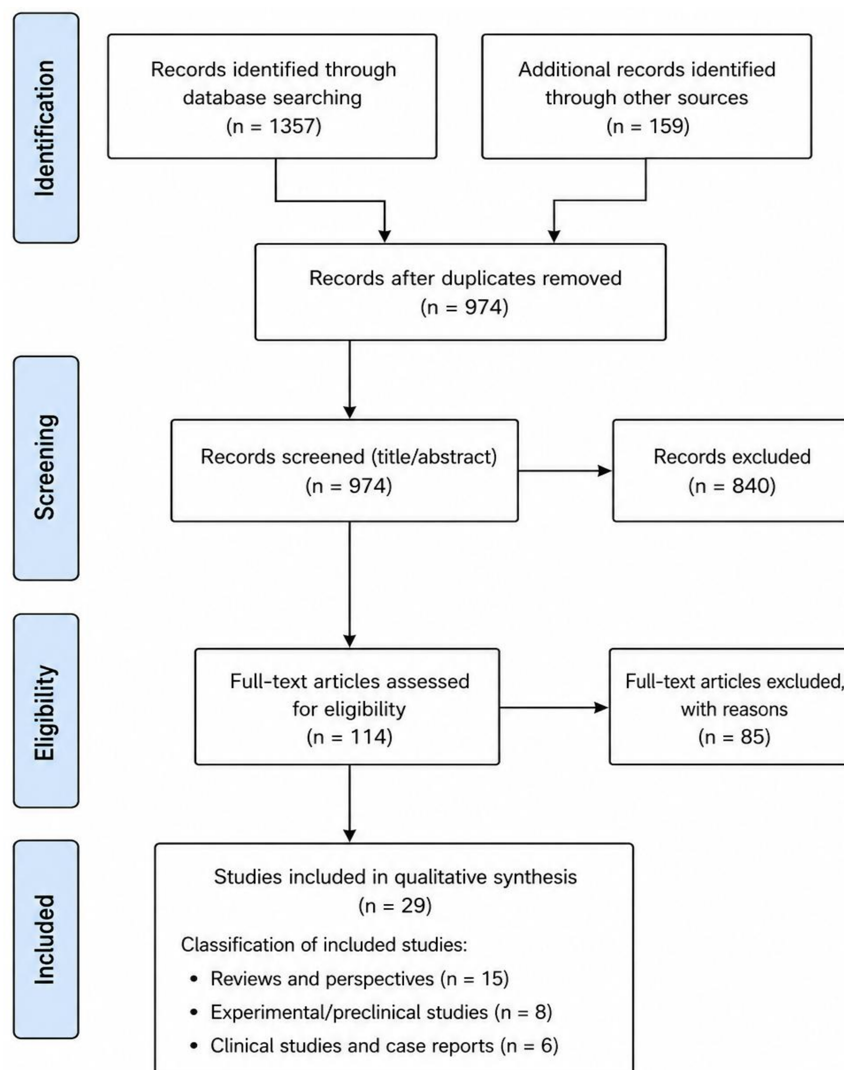

Figure 1. PRISMA flow chart of study selection

2. REVIEW METHODS

The review is based on an extensive PubMed literature search that included systematic reviews, review articles, clinical case reports, and experimental studies. The search included the following areas: partial heart transplantation in children; children with valvular heart disease; valve repair or replacement in children; pediatric preclinical trials; selected pediatric clinical cases; immunology as it relates to transplantation; and graft preservation. We focused on articles published since 2020, but included older literature to provide historical context.

We selected articles according to their relevance to the underlying goals of this review (Figure 1). In addition to articles found through PubMed, we also considered related publications suggested by the database. When a topic was only briefly addressed in a selected paper, we reviewed its reference list to identify additional relevant sources and expand the discussion. We excluded articles that were duplicates, unrelated, or only marginally relevant.

3. RESULTS & DISCUSSION

Partial heart transplantation (PHT) is a surgical procedure that involves the replacement of cardiac valves by the transplantation of the valve-bearing part of the heart. It combines elements of heart transplantation and valve replacement. In this method, the valvular graft remains viable and is anastomosed to the recipient tissue, allowing growth in pediatric patients while preserving the recipient's native ventricles (Rajab et al., 2021). Turek et al., (2024) created a PHT protocol before performing the first procedure. They proposed that "transplantation of a living homograft ("partial heart transplantation") will be associated with superior outcomes compared to currently available implants (homografts, bioprostheses, mechanical valves, non-valved conduits) in infants and young children. Subsequent results of the first surgeries appear to support this hypothesis.

Epidemiology

Congenital heart disease (CHD) is the most common congenital disability worldwide. Importantly, a significant proportion of CHD involves cardiac valves. Valvular abnormalities frequently accompany complex congenital heart defects and several genetic syndromes (Holst et al., 2017).

Over the past four decades, almost half of all available donor hearts were not used for transplantation. The amount differed by age group. It was lowest in infants and highest in adolescents. In the more recent period, from 2010 to 2022, the overall rate remained at 41.2%. One of the most common reasons for declining donor hearts was concern about suboptimal cardiac function. The second was logistical problems related to transporting a viable donor heart (Nguyen and Schiazza, 2023) As we present later in this paper, partial heart transplantation addresses these issues and may help improve the utilization of available donor organs.

Overall, valvular defects represent a frequent clinical problem in pediatrics, and current treatment strategies remain associated with high rates of reoperation and repeated interventions.

Other Growth-accommodating Approaches in Pediatric Valve Surgery

Ross procedure

Valve replacement with the Ross procedure involves using a patient's own pulmonary valve to replace the aortic valve and reconstructing the right ventricular outflow tract (RVOT) with a homograft or conduit. It offers excellent hemodynamics, growth potential, and no need for anticoagulation. The disadvantages are the complexity of the procedure. It necessitates operating on both great arterial roots, even though the disease was limited to the aortic valve. An important complication that affects the neo-aortic tract is autograft dilation, which leads to regurgitation and subsequent reinterventions. The RVOT conduit used to reconstruct the pulmonary outflow tract is also susceptible to complications. It can suffer from progressive stenosis and deteriorate over time. That gradual narrowing of the RVOT is particularly common in infants, who experience higher rates of early failure (Dib et al., 2025)

Orthotopic Heart Transplantation

Orthotopic heart transplantation (OHT) is a well-established procedure with a long period of follow-up, proving that the heart can grow with a pediatric recipient. Although heart transplantation is a life-saving surgery, it has several important limitations. Prolonged ischemic time beyond 4 hours may lead to ischemia–reperfusion injury that increases the risk of graft failure. OHT is also associated with the risk of primary graft dysfunction and graft rejection. Necessary lifelong immunosuppressive therapy has many adverse effects, including a dangerous risk of infections. Over time, the heart muscle can lose its function, leading to the need for another transplant within a few years. Graft availability is limited. Potential recipients may not qualify for heart transplantation if they do not meet the criteria, usually when their condition does not have a favorable prognosis. Additionally, heart transplantation requires compatibility between donor and recipient in terms of graft size and ABO and HLA blood group compatibility (Chrysakis et al., 2024).

Growth-accommodating implants

Researchers have made numerous attempts to adapt existing valve-replacement techniques for pediatric patients and to develop artificial valves that can accommodate somatic growth. However, these efforts have met with limited success. In the context of pulmonary valve replacement, researchers have explored several approaches. Venous valves, such as the Melody valve, can be modestly over-dilated to accommodate some patient growth, but they can expand only approximately 14%.

Another promising option for accommodating growth in patients after repair/replacement is the use of tissue-engineered heart valves (TEHVs), which consist of acellular, polymeric/biological scaffolds that facilitate the integration of the patient's own cells into the valve and accommodate somatic growth. An obstacle to the clinical use of TEHVs is the lack of precise control over how cells remodel after implantation, which can cause newly formed tissue to contract, leading to valve shortening and ultimately functional failure (Crago et al., 2023).

Although these approaches have shown encouraging results in preclinical studies, they share some important limitations with current valve replacement strategies. They do not fully recreate native anatomy. Foreign material continues to carry a risk of infective endocarditis.

Concept and Protocol of Partial Heart Transplantation

Observations of valve growth after full heart transplantation demonstrate the feasibility of Partial Heart Transplantation. The Ross procedure proved that the entire pulmonary root and the autograft can grow with the patient. Unfortunately, differences in the vessel wall's anatomical properties under left ventricular pressure can lead to dilatation and subsequent loss of valve function (Dib et al., 2025).

Cardiac surgeons have long utilized cardiac homografts and autohomografts. They performed the first operation with a valvar homograft in August 1962 (Barratt-Boyes, 1964). Those grafts were decellularized and avascular. Surgeons transplanted isolated valves without matching donors and recipients for HLA antigens or blood group (Mitchell et al., 1998). However, the development of partial heart transplantation (PHT) was made possible only in 2024, following preclinical experiments in piglet models. The anatomical, physiological, and immunological similarities between piglets and human infants make piglets an excellent experimental model. Their rapid growth over the first five months corresponds to human development up to adolescence, providing sufficient time to evaluate valve growth.

The protocol was created to outline the steps required throughout the pulmonary valve transplantation procedure. The protocol included preoperative care, donor procedure, recipient procedure, postoperative care, and monitoring heart function via echocardiogram (ECHO) and magnetic resonance imaging (MRI) (Medina et al., 2024a). Surgeons performed the procedures on seven piglets. One piglet died due to complications from anesthesia, but the others recovered well. Blood tests remained stable throughout the study. The piglets also doubled their body weight in about 2 months, which is a normal growth rate for healthy animals. The observed successful growth of transplanted valves in piglets suggested that PHT might be successful in pediatric patients (Medina et al., 2024b).

Clinical outcomes

The first Partial Heart Transplant procedure was clinically applied soon after animal trials. The first patient receiving such a transplant was an infant with persistent truncus arteriosus and irreparable truncal valve dysfunction. The recipient, an 18-day-old male, received a transplant from a 2-day-old female with hypoxic-ischemic brain injury. The donor and recipient were not ABO compatible. The recipient was type O, and the donor was type B. Immunosuppressive therapy with mycophenolate mofetil, tacrolimus, and steroids was administered to manage the ABO incompatibility. Highly accurate 3D-printed recipient`s heart models assisted preoperative planning. The surgery involved transplantation of the donor aortic and pulmonary roots while preserving the recipient’s native ventricles. The patient was extubated on postoperative day 6 and discharged on postoperative day 30. The only problem was the need for a gastrostomy tube. Follow-up echocardiograms confirmed adaptive growth of aortic and pulmonary valves. To assess the long-term outcome, doctors examined the recipient at 14 months of age. The valves, as expected, grew with the patient, and in echocardiography, their function was well sustained. Clinicians didn't observe signs of valve obstruction or regurgitation. The patient not only had good cardiac function but also met expected developmental milestones, yet tube feeding was still necessary due to a remaining oral aversion. The reported follow-up period indicated no symptoms of rejection (Turek et al., 2024).

Partial heart transplantation not only serves as valve replacement but also has introduced two promising new approaches into cardiac transplantology: domino transplantation and the split-root technique. Both approaches aim to better utilize donor tissue in

patients who need heart valve replacement. In domino transplantation, the recipient also becomes a donor; surgeons remove functional valves from the heart of a patient who is receiving a full orthotopic heart transplant. This procedure enables a single deceased-donor heart to help more than one patient. The split-root technique enables clinicians to use a donor heart that cannot serve for full transplantation. In these cases, surgeons can divide the heart into the aortic and pulmonary roots and transplant them into one or two different patients (Aykut et al., 2025).

Typical age for PHT is infancy. In a study of 19 cases, the median age at transplant was 97 days. However, some teenagers and adults also underwent PHT— the oldest recipient was 34 years old. As many as 13 out of 19 cases were domino surgery. According to this study, partial heart transplant (PHT) valves appeared to grow along with the recipients as they developed. This physiological growth is demonstrated by: the similar growth of transplanted heart valves to patients' native valves, increased leaflet size, and the absence of significant regurgitation or stenosis. As the study states, these observations suggest that annular expansion reflects true growth rather than passive dilation (Overbey et al., 2025).

Rejection Risk

Surgeons most often perform partial heart transplants in infancy to correct a congenital disability. Infants' immature immune system lacks antibodies against the donor's blood group. It is a very fortunate situation, which is creating a unique opportunity for transplantation. Studies show that infants who undergo heart transplantation experience fewer acute rejection episodes than older recipients (Boucek et al., 2024).

Moreover, heart valves are considered immunologically privileged. Immunological privilege is a feature of certain tissues such as the eyes, the nervous system, and articular cartilage, which—as a result of their limited regenerative capacity and the risk of severe consequences for the organism—are protected from damage caused by inflammatory processes (Hill et al., 2021).

Available evidence supports a lower risk of heart valve rejection, some coming from cases of orthotopic heart transplant (OHT). For example, a study of 118 OHT recipients found that 57 had at least one episode of rejection. In most cases, despite having an episode of rejection, there was no deterioration of aortic valve function. There was also no significant reduction in pulmonary valve function relative to pre-rejection function, and only about 31% of cases had trivial, clinically insignificant pulmonary insufficiency (Dudley et al., 2025).

Future directions

Advances in preservation methods

The most common method is static cold storage, which allows preservation for up to 48 hours and is the most attainable, low-cost approach. There are several other cryopreservation techniques. Some rely on very low temperatures, which can lead to the ice crystal formation that can damage tissue (supercooling, partial freezing). Others require large amounts of cryoprotective agents (CPAs). CPAs prevent cellular damage by osmotic pressure and ice crystallization. However, high concentration CPAs are potentially cardiotoxic. Isochoric preservation bypasses these drawbacks. It is a technique in which the tissue is maintained at a sub-freezing temperature in an inflexible container, thereby maintaining constant pressure during freezing. However, isochoric preservation is very expensive and still a developing technique (LaSala et al., 2025).

A further technique is vitrification with subsequent nanoworming. Vitrification rapidly cools the tissue. Nanowarming rapidly reheats it using iron oxide nanoparticles and a radiofrequency coil. Both steps prevent ice crystal formation. The heart valve seems to be an ideal candidate for vitrification due to its relatively thin tissue, which allows good penetration of cryoprotective agents and uniform cooling and warming. Potential storage time ranges from days to even years. A disadvantage of this method is the cost and the high volume of cryoprotective agent required (Finkbeiner et al., 2026)

Tissue preservation primarily relies on cold storage. Recent experimental studies now show that normothermic storage of the valve grafts can also be a safe option. But it requires a custom nutrient-rich solution to maintain tissue stability and homeostasis, while also preserving its metabolic function. Researchers found that the heart valve may remain viable for up to 7 weeks. Moreover, the valve structure remained intact in the first 3 weeks of the study. It suggests that normothermic storage could be a promising alternative to cryopreservation methods (Cordoves et al., 2025).

Researchers have proposed a new approach to preserve living valves under ex vivo conditions that mimic the human body's physiological environment. The concept aims to enable their long-term storage in biobanks and to create conditions for valve rehabilitation and immunomodulation. Valves would remain in good condition for long periods. Establishing a biobank of living valves would greatly increase the availability of matching valves and simplify the logistics of partial heart transplantation (Cordoves et

al., 2024). These findings suggest that new preservation strategies may improve graft availability and logistical flexibility of transplant grafts.

Immunomodulation and immunosuppression

One future approach in partial heart transplantation (PHT) might be to control the immune response directly at the graft, thereby reducing the need for systemic immunosuppression. Delivering immune-modulating agents into the graft could be achieved using hydrogels, nanoparticles, implantable devices, or a combination of these (Naaz et al., 2024). Such conditioning of donor tissue may involve the use of anti-inflammatory or tolerance-inducing agents, including IL-10, TGF-β, and CTLA4-Ig (Vervoorn et al., 2023). In particular, research demonstrates that IL-10 provides significant benefits when donor tissues are exposed to anti-inflammatory cytokines (Cordoves et al., 2024). Although these therapies are still experimental, they might help reduce or avoid the need for immunosuppressive drugs in PHT patients.

Long-term growth, durability, and surveillance

The future of partial heart transplant use will rely heavily on studies of long-term graft growth, durability, and surveillance. Early clinical experience has demonstrated that semilunar valves have the potential to support graft development after transplantation (Overbey et al., 2025).

To evaluate the relationship between valve growth, sustained valve function, and structural stability over an extended period, longer follow-up evaluations will be required. Research - using a standardized follow-up method (e.g., serial echocardiograms) - should investigate how long the valve will remain functional without deterioration and, if deterioration occurs, identify the cause(s) of the decline (McVadon et al., 2023).

Tissue engineering

One possible future application of partial heart transplantation is to perform the procedure with the use of tissue-engineered living heart valve substitutes. Review in Nature reports that fully bioengineered hearts still face challenges, including poor blood vessel growth, incomplete cell development, and ongoing issues with long-term electrical and mechanical function. Because of these challenges, routine transplantation of whole bioengineered hearts is not yet possible (Jebran et al., 2025). In contrast, heart valve tissue engineering appears to be much closer to clinical translation. In particular, decellularized and regenerative valve platforms have shown strong potential to support repair and remodeling and possibly to grow with the pediatric recipient. Future PHT procedures may use bioengineered valves. It would reduce donor tissue requirements and make that growth-adaptive repair more accessible (Fioretta et al., 2021).

3D virtual planning

Surgeons have used three-dimensional technologies in partial heart transplantation since their introduction into clinical practice. For instance, during the first successful PHT operation, doctors used 3D-printed models to plan the procedure. In a recent case study of partial heart transplantation in a 12-year-old child with severe stenosis of prosthetic valves, the surgeons relied on virtual 3D modeling techniques. It allowed the precise placement of reconstructed subvalvular structures without relying on patients' native anatomy (O'Hara et al., 2025).

Three-dimensional technologies can significantly enhance preoperative preparation, particularly in complex cases. The method is flexible and adaptable and does not require the actual manufacturing of any models. As such, virtual modeling is an excellent option for broader clinical use. All these experiences indicate that 3D technologies can be helpful in widespread PHT applications. Partial heart transplantation introduces to heart valve surgery the concept of transplantation of a living tissue capable of growth and adaptation. It addresses one of the most persistent challenges in pediatric cardiac surgery: the inability of currently available valve replacements to accommodate somatic growth. Preliminary clinical results are favorable. If long-term outcomes confirm the promising early results, PHT may significantly reduce the burden of repeated interventions that many children currently face throughout their lives.

Partial heart transplantation is not yet performed on a global scale. It may offer several important advantages over other reconstructive procedures and valve replacement strategies. These circumstances include situations in which donor hearts that are unsuitable for full transplantation but remain viable for partial graft use. In that case, the use of a partial cardiac graft is both ethically justified and clinically meaningful. A clear example is domino transplantation, in which a single donor heart may benefit two patients.

Similarly, split-root transplantation allows more efficient utilization of donor tissue. Together, these approaches demonstrate that PHT has the potential not only to improve patient outcomes but also to optimize donor organ utilization. At the same time, developing technologies offer hope for further development and wider implementation of this approach.

Advances in graft preservation, including normothermic storage, vitrification, and biobanking, may help overcome logistical barriers and expand access to suitable grafts. Integration of 3D virtual modeling and 3D surgical planning further illustrates how emerging technologies can facilitate the implementation of this complex procedure, improve preoperative planning, and support its wider adoption across specialized cardiac centers. In parallel, progress in bioengineered tissues and organs for transplantation may also improve the future availability of PHT (Table 1).

However, several limitations need to be acknowledged. Current clinical observations are based on a limited number of clinical cases and relatively short follow-up periods, which limit the ability to conclude about long-term durability, sustained valve growth, and late complications. Furthermore, PHT has not yet entered routine clinical practice, as its success depends not only on the availability of donor tissue but also on highly specialized surgical expertise and favorable clinical circumstances. Although heart valves appear to be less susceptible to rejection, recipients still require immunosuppressive therapy, while many proposed immunomodulatory strategies remain experimental. Heart valves may be particularly suitable for graft-directed immunomodulation because of their thin structure and their ability to tolerate prolonged preservation. Immunomodulation may represent a major step towards making PHT a more sustainable treatment option by reducing the complications associated with long-term immunosuppressive therapy. Therefore, larger clinical studies and longer follow-up will be necessary before PHT can be considered a widely established treatment option.

Table 1. Opportunities and Remaining Challenges in Partial Heart Transplantation

Domain	Opportunity	Remaining Challenge
Growth-adaptive repair	Physiological valve growth with the recipient	Unknown long-term durability
Reduced reinterventions	Potentially fewer valve replacement procedures	Lack of long-term outcome data
Immunological profile	Relative immune privilege of heart valves	Ongoing need for immunosuppression
Donor tissue utilization	Domino and split-root transplantation	Limited donor availability
Preservation	Longer preservation times than whole-organ grafts Possibility of biobanking and normothermic storage	Experimental technologies
Future graft sources	Tissue-engineered living valves	Not yet clinically available
Evidence base	Encouraging early clinical results	Small patient numbers and short follow-up

4. CONCLUSION

Partial heart transplantation represents a promising new approach in heart valve surgery. With particular potential among pediatric patients, by introducing a living valve that can grow and adapt. Initial clinical experience suggests that this approach may reduce the need for repeated valve replacement procedures and improve long-term outcomes in children. Although its current application remains limited, ongoing innovations may support broader implementation in the future. The available clinical evidence remains limited, and longer follow-up studies are required to establish its long-term safety.

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Informed consent

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Ethical approval

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Conflict of interest

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Data and materials availability

All data associated with this study will be available based on the reasonable request to corresponding author.

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