Partial Heart Transplant Procedure

Part 2 of 2

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In part one, the relevant anatomy and pathology related to truncus arteriosus was discussed as well as surgical options, shortage of donors, and development of the partial heart transplant (PHT) concept and first patient to undergo the procedure. For part two, the discussion will focus on the procedure, brief information regarding the domino and split-root transplants, immunosuppression and the future of the procedure.

PARTIAL HEART TRANSPLANT PROCEDURE

The PHT procedure involves harvesting healthy valves such as the aortic, atrioventricular, or pulmonary valves en bloc with a healthy margin of surrounding tissue and subsequently implanted into a recipient. The procedure begins with a sternotomy and establishing cardiopulmonary bypass just as with any type of open transplant procedure. The key difference from open heart transplant is that the recipient's native heart muscle is preserved, with only the diseased valve(s) excised and the donor valve(s) sutured into place.[1] The procedure is broadly described in three steps – surgeons dissect the existing truncus arteriosus, leaving the branches attached to the lungs; a new ascending aorta and valve are implanted using the donor tissue; and the donor pulmonary artery and valve are implanted and connected to the existing branch. The following description provides the details for implanting the aortic root and valve and pulmonary root and valve that was performed on Owen, the first patient to undergo a PHT that was described in the part one article published in the October 2025 edition of *The Surgical Technologist*. An animated video of the procedure is available on YouTube: youtube.com/watch?v=fiEzw1ECNnU.

LEARNING OBJECTIVES

- Describe the steps of the PHT procedure
- Discuss the concepts regarding the domino and split-root transplant procedures
- Evaluate the role of immunosuppression in PHT
- Discuss key topics that affect PHT including donor pool, logistics, regulation, and future trends

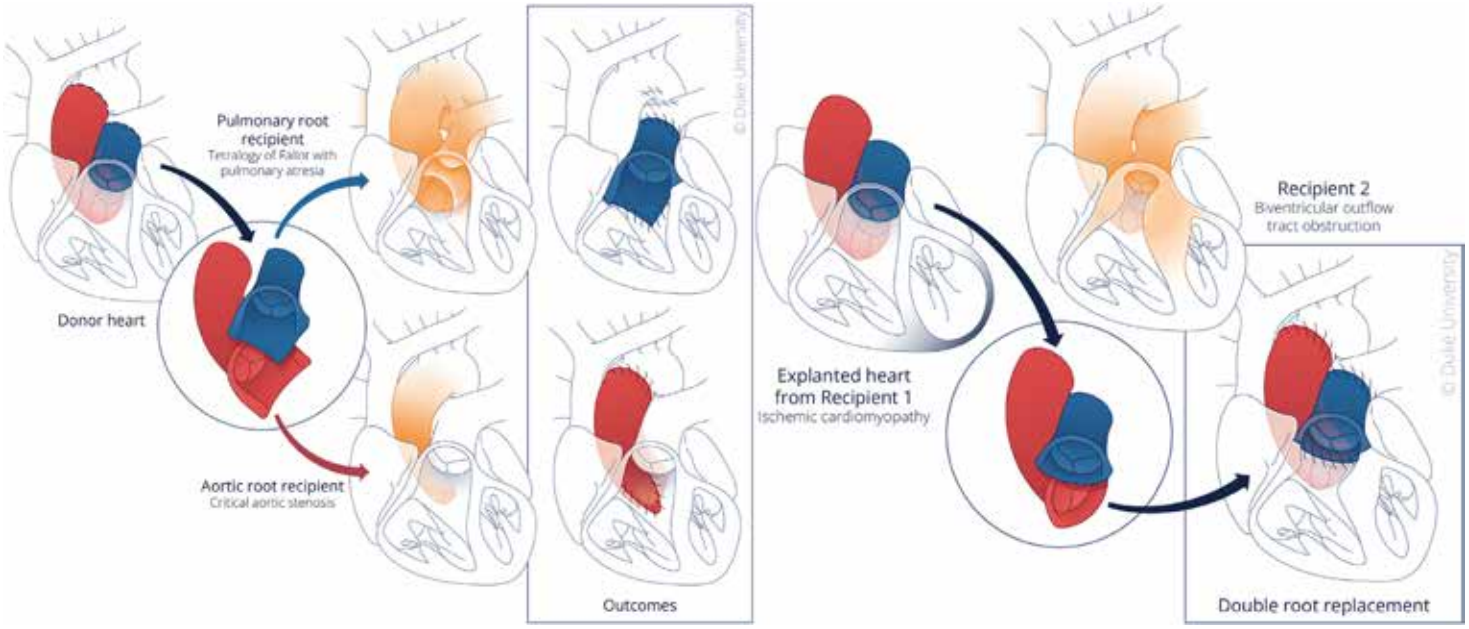

Figure 1 (A) Split root transplant 1 donor heart provides aortic and pulmonary root transplanted into two separate recipients, (B) Domino PHT whereby donor undergoes an open heart transplant, but the native aortic and pulmonary roots from the extracted heart can still function and are transplanted into a single recipient. The images apply to the PHT procedure. (Reproduced from Akykut et al, Partial heart transplantation promotes organ stewardships: domino hearts and split roots, *Annals of Thoracic Surgery Short Reports* (2024), doi: 10.1016.j.atssr.2024.07.033, under the terms of the Creative Commons Attribution 4.0 International License).

KEYWORDS

coronary buttons, domino PHT, immunosuppression, Organ Procurement and Transplantation Network, split-root procurement, truncus arteriosus, vitrification.

DEFINITIONS

Calcineurin inhibitors: A class of immunosuppressant drugs that block the activation of calcineurin, enzyme involved in the immune system, to prevent it from activating T cells, thus inhibiting the production of inflammatory cytokines. Cyclosporine is a calcineurin inhibitor.

Steps of the PHT Procedure (procedural steps derived from Prabhu et al, Partial heart transplantation: early experience with pediatric heart valve replacements that grow, *Circulation* (2025), doi: 10.1161/CIRCULATIONAHA, 124.072626 and Turek et al, Partial heart transplant in a neonate with irreparable truncal valve dysfunction, *JAMA* (2024), doi: 10.1001/jama.2023.23823)

1. The donor heart is extracted by the donor surgical team.
   a. The surgeon harvests the aortic and pulmonary roots and valves, along with the connected arteries, including a margin of ventricular septum and atrial tissue to preserve the delicate tissue structures.
   b. The valves and roots are prepared for grafting by the surgeon.
2. Sternotomy is performed and cardiopulmonary bypass established.
   a. The pulmonary artery ostia and coronary artery buttons are dissected.
   b. The diseased aortic and pulmonary roots and valves are excised from the recipient, essentially excising the truncal valve from the combined outflow tract leaving the branches to the lungs in

place. This is completed in preparation for creating separate pulmonary and systemic circulation.

c. The subvalvular apparatus, including the chordae tendineae that supports the valves, is preserved and the surgeon leaves a small margin of native tissue at the base of the valves to aid in suturing the donor tissue.

3. The first end-to-end anastomosis to be completed is suturing the proximal end of the ascending aorta and valve into place using a circumferential running suture.
4. The distal portion of the donor aortic root with valve is anastomosed.
   a. The distal portion is also placed using a circumferential running suture. A rim of native valvular tissue is left to avoid damage to the conduction tissue and coronary arteries.
   b. The leaflet edges are sutured to the preserved subvalvular tissue to reconstruct the apparatus. The donor tissue at the distal portion also closes the ventricular septal defect.
   c. The coronary artery buttons are reimplanted and attached to the donor aortic root using circumferential running suture.
5. After the ascending aorta and valve are sutured into place, the surgeons enlarge the right ventricular outflow tract.
6. Next, the donor pulmonary root is transplanted by attaching the section of the pulmonary artery and valve tissue to the branch that leads to the lungs and down to the right ventricle. The same circumferential suture technique is used. The right ventricle is connected to the pulmonary arteries during this step of the procedure. (Figure 1, B)
7. The surgeons connect the donor tissue's major blood vessels to the recipient's blood vessels including the coronary arteries, inferior vena cava, left atrium, pulmonary artery and superior vena cava.
8. Both valves are tested in routine fashion to ensure they are properly working and there are no leaks.
9. The heart is restarted, the patient is gradually taken off the cardiopulmonary bypass machine, and the chest is closed.

The prognosis is that the donor vessels and valves will grow as the infant grows, thus avoiding future surgeries.

> The PHT procedure involves harvesting healthy valves such as the aortic, atrioventricular, or pulmonary valves en bloc with a healthy margin of surrounding tissue and subsequently implanted into a recipient.

DOMINO PHT AND SPLIT ROOT PROCUREMENT

Domino PHT and split root procurement are two approaches that contribute to helping to solve the shortage of donor tissue. The valves from the native hearts of many recipients of orthotopic heart transplant (OHT) are structurally normal and therefore, normally function. The domino PHT concept involves excising the aortic and pulmonary roots from the native heart of the donor and implanting into the recipient following the steps of the procedure described above. (Figure 1, B) The domino PHT has been performed multiple times since the first PHT.[3]

The split root procurement concept involves transplanting the aortic root into one patient and the pulmonary root into a second patient. (Figure 1, A) For example, a donor heart that has decreased ventricular function, but normally functioning aortic and pulmonary valves can provide the aortic root for a neonate with aortic stenosis and the pulmonary root for a neonate suffering from tetralogy of Fallot and pulmonary stenosis.[1]

IMMUNOSUPPRESSION

The main disadvantage of PHT is the need for immunosuppression. OHT provides some guidance in regard to the long-term risks from immunosuppression including neurotoxicity, post-transplant lymphoproliferative disease caused by Epstein-Barr virus, post-transplant opportunistic infection, and renal dysfunction caused by calcineurin inhibitors.[1,3] Usually, when the immune system rejects a donor heart, it is rejecting the heart muscle, However, the blood vessels and valves of the heart consist of tissue that does not have as many markers, making the tissue not as reactive.[4] Most OHT patients are required to take two immunosuppressive drugs. At Duke University Medical Center, the surgeons post-operative immunosup-

pression therapy begins with steroids and two immunosuppressive drugs eventually transitioning to one low dose immunosuppressive drug.[1] It was reported that it was only necessary for Owen to take one low-dose immunosuppressive drug and a patient that underwent a PHT remains drug free, indicating an excellent match between the donor and recipient.[4] Researchers acknowledge that ongoing work is needed to determine the optimal level and duration of post-operative immunosuppression with the goal that PHT patients will not have to take an immunosuppressive drug. [1,3]

DONOR POOL

Part one of the article discussed the challenges of donor shortages. The issue to consider is how to increase the donor pool for PHT. The primary source of donor hearts for PHT is the Organ Procurement and Transplantation Network (OPTN).[5] However, because of the limited number of donor hearts, using the OPTN hearts for PHT further decreases the number of hearts needed for OHT. An analysis of the United Network for Organ Sharing (UNOS) database showed that the OPTN does not distribute 30 – 40 infant and 40 – 80 toddler hearts annually.[5] Typical reasons for the donor hearts not being used include donation after cardiac death, logistical issues, and ventricular dysfunction.[5] These hearts could be used for PHT because the valves are structurally and functionally normal. Rajab indicates that donor hearts that are not registered with the OPTN could be used for PHT.[5] He also indicates that donor hearts are not registered with the OPTN if organ procurement organizations (OPOs) determine that the allocation is exceedingly low that often occurs with neonates that weigh less than 5 kg.[5]

LOGISTICS

Another barrier to establishing PHT as a routine procedure is logistics. A nationwide system is lacking for allocating PHT donors to identified recipients. Currently, healthcare facilities with a PHT program independently manage the logistical challenges of obtaining PHT donors including the challenge of addressing distance and time.[1,5] Additional research is needed regarding the viability of partial heart allografts that are placed in cold storage.[1] Until viability has been established through rigorous research methods, the distance and time constraints remain.[1,5] Additionally, establishing a nationwide system would contribute to efficient distribution of partial heart allografts. The distribution system could be organized similar to the processes that the OPTN has in place.[5]

Future directions of PHT are focused on techniques of preserving the tissue including cold storage and vitrification and the development of new operations.

REGULATION

The regulatory environment in regard to the development and use of PHT is key to its success as being recognized as a routine procedure. Beginning 2023, the U.S. Food and Drug Administration (FDA) has regulated PHT as tissue under regulation 21 CFR Part 1271 Human Cells, Tissues, and Cellular and Tissue-Based Products (HCT/Ps).[1] This was selected after meetings between the FDA, Health and Human Services, and OPTN.[1] However, Prabhu et al, suggests there are reasons to change the policy by considering PHT analogous to whole organ transplants because of similar logistical issues.[1] The FDA does not have a national system for procurement and allocation of PHTs, as compared to the OPTN that is effective in identifying and screening organ donors and facilitating the logistics.[1] It is suggested that policy changes are made to reflect PHTs as organs to have a coordinated nationwide system because time is of the essence when identifying critically ill neonate recipients.[1]

FUTURE OF PHT

Future directions of PHT are focused on techniques of preserving the tissue including cold storage and vitrification and the development of new operations. The question in regard to cold storage is if the grafts can be safely stored in this manner that preserves cellular viability. Identifying a safe cold stor-

age method would have an important impact on decreasing the expediency required to identifying a suitable partial heart donor at the time of surgery.[1] Research has shown that PHT allografts placed in cold storage, such as the University of Wisconsin solution, keep cellular viability for up to 48 hours.[6] Valvular tissue may be more resistant to ischemia, but further research is needed to identify the exact point in time when the viability of cells no longer exists.

The research team at Duke University Medical Center discussed another technique for possibly extending the viability of the tissue cells called vitrification that involves using cryoprotective agents and rapid cooling to prevent ice crystal formation, thus preserving the tissue.[1] The technique has been used to keep human embryos alive for more than 13 years. It could therefore be assumed that the technique can be used to preserve cellular viability and the structure of the partial heart allografts.[1] Before this could be considered for use questions to be answered include the cost of the technology, the correct temperature, and the regulation of the technique.

New procedures to be explored include living atrioventricular valve replacement, transplantation of blood vessels, and transplantation of parts of the cardiac chambers. The challenge for living atrioventricular valve replacement involves preserving the subvalvular apparatus.[1] If this is overcome and the technique refined, it could be a major advancement in treating pediatric patients that present with severely dysfunctional atrioventricular valvular disease.

Another possible application of PHT is transplanting donor blood vessels. The primary advantage, as previously stated for PHT, is they would grow with the pediatric patient. This could be another important step forward in treating children with Tetralogy of Fallot or pulmonary atresia who require reconstruction of the branch pulmonary arteries.[1,5]

Lastly, another application of PHT to be explored is transplantation of parts of the cardiac chamber. This would require the surgeon to perform a free grafting of the myocardium that is supplied by a donor coronary artery.[5] The technique could be used to treat single ventricle defects or to replace the infarcted section of the ventricle.

SUMMARY

The need to treat children who are suffering from critical valvular diseases with improved surgical methods is critical. The mainstream methods of using bioprosthetic and mechanical valves as well as cryopreserved homografts are inadequate because they place the patient in the position of having to undergo multiple surgical procedures. PHT has been shown to be a safe surgical option in which multiple patients are living normal lives with the valves growing as they grow. Research needs to focus on post-operative immunosuppression drug therapy and cold storage, or other storage methods for living partial heart allografts that preserve cellular viability.

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Partial Heart Transplant Procedure, Part 2

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1. **Which of the following is the first anastomosis to be completed?**
   a. Distal pulmonary root
   b. Distal aortic root
   c. Proximal pulmonary root
   d. Proximal aortic root

2. **What suture technique is used for the anastomoses?**
   a. Purse-string
   b. Continuous running
   c. Interrupted mattress
   d. Figure-of-8

3. **What is used to close the ventricular septal defect?**
   a. Aortic patch
   b. Synthetic patch
   c. Septal occluder
   d. Aortic root distal tissue

4. **The split root procurement involves excising the valves and transplanting from the heart of a pediatric patient undergoing orthotopic heart transplant.**
   a. True
   b. False

5. **What type of anastomosis is performed for the aortic and pulmonary roots?**
   a. End-to-side
   b. Roux-en-Y
   c. End-to-end
   d. Side-to-side

6. **Which chamber of the heart is attached to the pulmonary arteries after the pulmonary root is transplanted?**
   a. Right ventricle
   b. Left ventricle
   c. Right atrium
   d. Left atrium

7. **The Duke University Medical Center research team indicated the immediate post-operative immunosuppression drug therapy begins with:**
   a. no steroids, two immunosuppressive drugs.
   b. steroids, one immunosuppressive drug.
   c. steroids and two immunosuppressive drugs.
   d. no steroids, two immunosuppressive drugs.

8. **The analysis of the UNOS database showed that OPTN does not distribute _____ - _____ number of infant hearts annually for various reasons.**
   a. 20 - 30
   b. 30 – 40
   c. 40 – 50
   d. 50 – 60

9. **What federal agency currently regulates PHT as tissue?**
   a. U.S. Food and Drug Administration
   b. Agency for Healthcare Research and Quality
   c. U.S. Department for Health and Human Services
   d. National Institutes of Health

10. **Research has indicated that PHT allografts can remain viable in cold storage for up to _____ hours.**
    a. 12
    b. 24
    c. 36
    d. 48

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