Partial heart transplantation of atrioventricular valves in complete atrioventricular septal defect—simulation of techniques using silicone-molded heart models

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Left atrioventricular valve (AVV) regurgitation in neonates and infants is a significant cause of mortality, morbidity, and reoperation.1 Surgical treatment includes AVV repair; however, options following failure of repair are limited to valve replacement. This is an undesirable long-term solution due to the lack of growth potential and long-term durability of these valve substitutes. Stented bovine jugular vein grafts, which can be balloon-dilated over time, have been shown promise2; however, there is an urgent need for a heart implant that is durable and potentially limits reoperations in this challenging cohort. Partial heart transplantation uses living homografts3 and has been hypothesized to treat congenital diseases involving semilunar valve dysfunction such as truncus arteriosus4 and been simulated on 3-dimensional (3D)-printed models to assess feasibility and to refine surgical techniques.5 We hypothesized that this methodology could be used to explore the feasibility of partial heart transplantation of the AVV in complete atrial septal defect (AVSD) using silicone-molded heart models.

METHODS

Institutional review board approval was not required for this manuscript. Silicone-molded hearts of complete AVSD and a normal infant heart were acquired from the Hospital for Sick Children, Toronto. These models are superior to conventional directly printed 3D models as they have tissue properties that resemble real human tissue better.6 Models included coronary arteries and all heart valves to increase the fidelity of the model. Operations for partial heart transplantation were developed in multiple iterations to identify and refine the procedure (Figure 1).

RESULTS

Operation 1 involves harvesting of the AVV from the donor heart en bloc. An incision is made along the AV groove, avoiding damage to the anulii. The leaflets are harvested en-bloc with a generous portion of the ventricular septum along with a rim of atrial tissue and septum. The AVV chords are detached, and aortic and pulmonary roots are removed (Figure 1, B).

Operation 2 involves the preparation of the recipient heart and reimplantation of the donor AVV. First, the AVV is removed from the recipient heart with preservation of a 3-mm rim of leaflet tissue at the base of the native AVV. The native subvalvular apparatus is also preserved by leaving a 3- to 5-mm rim native tissue from the leaflet edge, which is left attached to the primary chords (Figure 2, A).

The ventricular septal defect (VSD) component of the AVSD is measured and the donor septum is cut to match, with caution paid to the outlet septum to avoid potential left ventricular outflow tract obstruction. Alternatively, a patch can be used to close the VSD. A running suture is commenced at the deepest point of the VSD with each end terminating in the right atrium. A running suture is commenced at the deepest point of the VSD with each end terminating in the right atrium.
The left followed by right AVVs are sutured in with a circumferential stitch using the rim of native AV tissue left to avoid potential damage to conduction tissue or coronary arteries. The leaflet edges are then sutured to the preserved subvalvular tissue reconstructing the subvalvular apparatus. The AVVs are tested in the routine fashion to ensure competency. Patch closure of the atrial septal defect is then performed.

DISCUSSION

3D models have been used successfully in the simulation and rehearsal of operations used to treat challenging congenital heart defects. The main advantage is that novel procedures can be trialled and refined to assess feasibility before patient application. Here we address the issues of AVV replacement in the failed valve in complete AVSD using the concept of partial heart transplantation. This technique could be adopted in diseases involving the AVVs including congenital mitral stenosis, tricuspid atresia, Ebstein anomaly, or unbalanced AVSD.

Although promising, developing this procedure highlighted some technical challenges, particularly with addressing the subvalvular apparatus and avoidance of AV block. Albeit challenging, the authors believe that the technique described best deals with these concerns however alternatives were considered:

1. Reimplantation of donor subvalvular apparatus [end-to-end] (Figure 2, B): The donor AVVs are harvested with the whole subvalvular apparatus, including papillary muscles. These are then sutured to the native papillary muscles end-to-end. This technique would likely cause papillary muscle ischemia and fibrosis, leading to delayed AVV failure.

2. Side-by-side anastomosis of papillary muscles (Figure 2, C): Similar to the aforementioned technique, the whole subvalvular apparatus is harvested with the donor/recipient papillary muscles anastomosed side-by-side. It would be expected that the native papillary muscle would continue to grow with the heart.

3. Chord reimplantation (Figure 2, D): The donor subvalvular apparatus is resected (preserving leaflets only) with neochords used to connect the donor leaflets with the recipient papillary muscles. In addition to being technically challenging, this does not address the limitation of growth or prosthetic material failure over time.

Another consideration is the impact of immunosuppression in partial heart transplantation, which has shown...
promise in semilunar valve replacement. Stopping immunosuppression would likely be more problematic due to cessation of growth of the donor valve. This would effectively make the replaced valve a nongrowing homograft and lead to the loss of one of the main benefits of partial heart transplantation. Table E1 compares partial heart transplants with homografts and orthotopic heart transplants. The next steps in this project will involve in vivo testing in piglets to test the feasibility and durability of the aforementioned techniques.

**CONCLUSIONS**

Silicone-molded models were used to develop a new technique and assess the feasibility of partial heart transplantation of AVVs in complete ASVD.

**Conflict of Interest Statement**

The authors reported no conflicts of interest. The editors and reviewers of this article have no conflicts of interest.

**References**


**FIGURE 2.** Possible techniques for dealing with subvalvular apparatus during partial heart transplantation. A, Harvest of recipient AVV leaflets with preservation of the subvalvular apparatus. Note: Rim of valve tissue at leaflet edge is preserved to facilitate sputtering of donor leaflet to recipient subvalvular apparatus. B, Harvest of donor leaflets with chords and head of papillary muscle followed by end-to-end anastomosis to recipient papillary muscles. C, Side-by-side anastomosis of donor and recipient papillary muscles. D, Harvest of donor leaflets only and chord reimplantation with neochords. AVV, Atrioventricular valve.
TABLE E1. Comparison table of the biological donor substitutes that could be used for the replacement of atrioventricular heart valves

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<tr>
<th></th>
<th>Homograft</th>
<th>Partial heart transplant</th>
<th>Orthotopic heart transplant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Graft</strong></td>
<td>Heart valve</td>
<td>Heart valve</td>
<td>Whole heart</td>
</tr>
<tr>
<td><strong>Donor</strong></td>
<td>Cadaver</td>
<td>Organ donor</td>
<td>Organ donor</td>
</tr>
<tr>
<td><strong>ABO typing</strong></td>
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<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Preservation</strong></td>
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<td>Hours</td>
<td>Hours</td>
</tr>
<tr>
<td><strong>Recipient immunosuppression</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td><strong>Functional valve cells</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Growth and self-repair</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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