The modification of a right ventricle to pulmonary artery conduit for the Norwood procedure reduces the unintended shunt-related events.

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No Disclosure
Right ventricle-to-pulmonary artery shunt versus modified Blalock-Taussig shunt in the Norwood procedure for hypoplastic left heart syndrome – influence on early and late haemodynamic status

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Abstract

Objective: The aim of this study was to assess changes in early and late haemodynamic status after the Norwood procedure (NP), caused by the implementation of right ventricle-to-pulmonary artery shunt (RV-PA). Methods: A consecutive series of 68 children with hypoplastic left heart syndrome underwent NP: Group 1 (n = 31) with the application of a modified Blalock-Taussig shunt and Group 2 (n = 37) with RV-PA. Haemodynamic data from the early postoperative period (72 h after the operation) and cardiac catheterisation data, as well as blood tests before the hemi-Fontan procedure (HF) were analysed. Univariate (χ² test, Mann–Whitney’s and Student’s t-tests) and multiple regression analysis were carried out. Results: In Group 1, circulatory collapse requiring resuscitation occurred in 15 (48.4%) children, within 72 h after the procedure. The resuscitation was unsuccessful in nine (29%) cases. The operative mortality (30 days) was 35%. In Group 2, two (5%) children died within the early and two (5%) within the late postoperative period. The postoperative course in the remaining children from Group 2 was uneventful. In Group 2 there was a significantly higher mean diastolic pressure after NP (P < 0.05). The arterial pulse pressure after NP was significantly lower in Group 2 (P < 0.05). Before HF, the application of RV-PA was associated with a lower Qp:Qs ratio (P = 0.026), lower aortic pulse pressure (P = 0.004) and lower aortic oxygen saturation (P = 0.039). Conclusions: A stable haemodynamic status due to independent coronary perfusion, higher diastolic and lower pulse pressure is the most advantageous effect of RV-PA, resulting in a lower mortality and morbidity after NP. A lower Qp:Qs ratio eliminates the danger of the ventricular volume overload and ensures good conditions for the development of the pulmonary circulation before HF.
Mean arterial diastolic pressure 72 h after the procedure

The total heart work was 0.0311 J/cycle in the BTS model versus 0.0279 J/cycle in the RVPA model.
Norwood with right ventricle-to-pulmonary artery conduit is more effective than Norwood with Blalock–Taussig shunt for hypoplastic left heart syndrome: mathematic modeling of hemodynamics

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Abstract

Objective: The introduction of right ventricle to pulmonary artery (RV-PA) conduit in the Norwood procedure for hypoplastic left heart syndrome resulted in a higher survival rate in many centers. A higher diastolic aortic pressure and a higher mean coronary perfusion pressure were suggested as the hemodynamic advantage of this source of pulmonary blood flow. The main objective of this study was the comparison of two models of Norwood physiology with different types of pulmonary blood flow sources and their hemodynamics. Method: Based on anatomic details obtained from echocardiographic assessment and angiographic studies, two three-dimensional computer models of post-Norwood physiology were developed. The finite-element method was applied for computational hemodynamic simulations. Norwood physiology with RV-PA 5-mm conduit and Blalock–Taussig shunt (BTS) 3.5-mm shunt were compared. Right ventricle work, wall stress, flow velocity, shear rate stress, energy loss and turbulence eddy dissipation were analyzed in both models. Results: The total work of the right ventricle after Norwood procedure with the 5-mm RV-PA conduit was lower in comparison to the 3.5-mm BTS while establishing an identical systemic blood flow. The Qp/Qs ratio was higher in the BTS group. Conclusions: Hemodynamic performance after Norwood with the RV-PA conduit is more effective than after Norwood with BTS. Computer simulations of complicated hemodynamics after the Norwood procedure could be helpful in establishing optimal post-Norwood physiology.
RESULTS

Transplantation-free survival 12 months after randomization was higher with the RVPA shunt than with the MBT shunt (74% vs. 64%, \( P = 0.01 \)). However, the RVPA shunt group had more unintended interventions (\( P = 0.003 \)) and complications (\( P = 0.002 \)). Right ventricular size and function at the age of 14 months and the rate of nonfatal serious adverse events at the age of 12 months were similar in the two groups. Data collected over a mean \((\pm SD)\) follow-up period of 32\pm11 months showed

Comparison of Shunt Types in the Norwood Procedure for Single-Ventricle Lesions

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Minmin Lu, M.S., Caren S. Goldberg, M.D., Sarah Tabbutt, M.D., Ph.D.,
Peter C. Frommelt, M.D., Nancy S. Ghanayem, M.D.,
Peter C. Laussen, M.B., B.S., John F. Rhodes, M.D., Alan B. Lewis, M.D.,
Seema Mital, M.D., Chitra Ravishankar, M.D., Ismee A. Williams, M.D.,
Carolyn Dunbar-Masterson, B.S.N., R.N., Andrew M. Atz, M.D.,
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Kirk R. Kanter, M.D., James Jaggers, M.D., Jeffrey P. Jacobs, M.D.,
Catherine Dent Krawczeski, M.D., Nancy Pike, R.N., Ph.D.,
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and J. William Gaynor, M.D., for the Pediatric Heart Network Investigators

The objective

- to present how changes in the technique of the RVPAc implantation during the Norwood stage I may influence the results and necessity of unintended catheter-based and surgical interventions in a single center experience
Material

• Cohort of 101 HLHS patients who underwent Norwood stage I between 2011-2014 in Department of Pediatric Cardiac Surgery, Jagiellonian University, Krakow, Poland divided into 3 groups according to RVPAc strategy
• Patients with variant-HLHS and hybrid procedures were excluded
• Retrospective nature of data collecting
Norwood stage I palliation

- Reconstruction of the aorta with pulmonary homograft patch
- Rapid cooling until ECG isoelectric line
- DHCA
- pH-stat strategy
- Ht value - about 30%
- No MUF
- Avoiding high doses of inotropes
Norwood stage I – reconstruction of aortic arch with pulmonary homograft patch
Norwood I – ascending aorta (2 mm)
Norwood stage I – stent implantation into native diminutive aorta
RVPAc - concept - evolution

- Left RVPAc with homograft patch
- Right RVPAc with homograft patch
- Reinforced right RVPAc with homograft patch
- „Dunk“ reinforced right RVPAc with homograft patch
- „Dunk“ reinforced right RVPAc with direct distal anastomosis
Disadvantages of l-RVPAc

- Contraction of RV wall
- Cloths formation
- Tissue ingrowth
- Kinking of shunt

RVPAc concept evolution

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Bigger RV ventriculotomy
Left 5 mm RVPAc with homograft cuff

- Significant ventriculotomy
- Difficult approach to the distal part of conduit during the second stage
- Potential compression of enlarged ascending „neoaorta” to RPA
Left RVPA conduit
Right RVPA conduit
RV PA concept - evolution

- Left RVPAC with homograft patch
- Right RVPAC with homograft patch
- Reinforced right RVPAC with homograft patch
- "Dunk" reinforced right RVPAC with homograft patch
- "Dunk" reinforced right RVPAC with direct distal anastomosis
Right RVPAc with homograft patch

- Potential compression of conduit between sternum and free wall of the RV
- Big ventriculotomy or proximal stenosis of conduit
- Possibility of proximal stenosis of PA’s
- Possibility of damaging conduit during resternotomy
- Longer conduit

- Easy access to PA’s confluens
RV PA concept - evolution

Left RVPAc with homograft patch

Right RVPAc with homograft patch

Reinforced right RVPAc with homograft patch

„Dunk” reinforced right RVPAc with homograft patch

„Dunk” reinforced right RVPAc with direct distal anastomosis
RVPAc - concept - evolution

- Left RVPAc with homograft patch
- Right RVPAc with homograft patch
- Reinforced right RVPAc with homograft patch
- „Dunk” reinforced right RVPAc with homograft patch
- „Dunk” reinforced right RVPAc with direct distal anastomosis
Modified „dunk” technique

- 3 single sutures through the full thickness of RV wall and the 3 ring of RVPAc
- 1 continuous superficial, hemostatic suture
- Cutting flush with the external ring
- 4 mm ventriculotomy
Modified „dunk” technique
Norwood – right reinforced RVPAc proximal fixation
Norwood – right reinforced RVPAc proximal fixation
Norwood – right reinforced RVPAc proximal fixation
Modified „dunk” reinforced right RVPAc with homograft patch

- Smaller ventriculotomy
- Elimination of proximal stenosis of conduit
- Easy access to PA’s confluence
- Possibility of damage of conduit during sternotomy - gore-tex patch covered conduit
- Possible proximal stenosis of PA’s
Norwood with reinforced „rightward”
RVPAc – situs inversus
RVPAc - concept - evolution

Left RVPAc with homograft patch

Right RVPAc with homograft patch

Reinforced right RVPAc with homograft patch

„Dunk” reinforced right RVPAc with homograft patch

„Dunk” reinforced right RVPAc with direct distal anastomosis
Rotation of proximal parts of PA’s “bow tie” effect
Rotation of proximal parts of PA’s “bow tie” effect
Rotation of proximal parts of PA’s „bow tie” effect
Rotation of proximal parts of PA’s „bow tie” effect
Reinforced RVPAc with homograft cuff
RVPAc – implantation of distal part
„Dunk” reinforced right R-VPAc with direct distal anastomosis

- Elimination of torsion of proximal aspects of PA’s
- Elimination of calcification of homograft patch
- Better pulmonary artery growth (?)
Removing of the RVPAc ???
## Cohort of patients with HLHS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Left RVPAc [n=32]</th>
<th>Right RVPAc [n=28]</th>
<th>Right reinforced RVPAc [n=41]</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [days]</td>
<td>10.7±7.22</td>
<td>12.1±6.94</td>
<td>9.8±7.23</td>
<td>NS</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>3.3±0.27</td>
<td>3.3±0.63</td>
<td>3.2±0.35</td>
<td>NS</td>
</tr>
<tr>
<td>Gestational age [weeks]</td>
<td>38.3±1.47</td>
<td>39.9±1.42</td>
<td>38.9±1.23</td>
<td>NS</td>
</tr>
<tr>
<td>Prenatal diagnosis</td>
<td>17/32</td>
<td>16/26</td>
<td>24/41</td>
<td>NS</td>
</tr>
<tr>
<td>Aortic atresia</td>
<td>16/32</td>
<td>16/28</td>
<td>20/41</td>
<td>NS</td>
</tr>
<tr>
<td>Diameter of ascending aorta [mm]</td>
<td>3.5±1.72</td>
<td>3.1±2.31</td>
<td>3.2±0.52</td>
<td>NS</td>
</tr>
<tr>
<td>Diameter of aortic arch [mm]</td>
<td>4.6±1.11</td>
<td>4.8±1.32</td>
<td>4.4±1.54</td>
<td>NS</td>
</tr>
<tr>
<td>Associated diagnosis</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>NS</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time [min.]</td>
<td>108±49.2</td>
<td>105±46.7</td>
<td>98±44.6</td>
<td>NS</td>
</tr>
<tr>
<td>DHCA [min.]</td>
<td>44.5±9.31</td>
<td>41.6±11.20</td>
<td>39.7±9.12</td>
<td>NS</td>
</tr>
<tr>
<td>Early mortality rate [%]</td>
<td>9.3</td>
<td>14.2</td>
<td>7.3</td>
<td>NS</td>
</tr>
</tbody>
</table>
## Shunt-related reinterventions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>L-RVPAC [n=29]</th>
<th>R RVPAC [n=24]</th>
<th>RR RVPAC [n=38]</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interventional cath-based</td>
<td>10</td>
<td>6</td>
<td>0</td>
<td>0.002 0.01</td>
</tr>
<tr>
<td>Median time to reintervention [days]</td>
<td>65 [2-119]</td>
<td>57 [3-139]</td>
<td>-</td>
<td>NS</td>
</tr>
<tr>
<td>Surgical</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>NS</td>
</tr>
<tr>
<td>PA’s related interventions at hemi-Fontan</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>Additional procedures at Hemi-Fontan</td>
<td>3</td>
<td>3</td>
<td>8</td>
<td>NS</td>
</tr>
</tbody>
</table>

RVPAC concept evolution

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Pulmonary arteries diameter assessed before stage II palliation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>L-RVPAc [mm]</th>
<th>R-RVPAc [mm]</th>
<th>RR-RVPAc [mm]</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal LPA</td>
<td>3.91±0.2</td>
<td>4.01±0.03</td>
<td>4.21±0.2</td>
<td>0.007</td>
</tr>
<tr>
<td>Distal LPA</td>
<td>4.89±0.3</td>
<td>4.97±0.2</td>
<td>5.08±0.3</td>
<td>0.02</td>
</tr>
<tr>
<td>Proximal RPA</td>
<td>3.97±0.2</td>
<td>4.04±0.3</td>
<td>4.33±0.2</td>
<td>NS</td>
</tr>
<tr>
<td>Distal RPA</td>
<td>5.48±0.1</td>
<td>5.45±0.2</td>
<td>5.65±0.3</td>
<td>NS</td>
</tr>
</tbody>
</table>
Shunt-related reinterventions

L RVPAc [n=10]

6 cath-based interventions

1 ballooning of prox. and dist. shunt

2 balloon plastic of proximal shunt

3 stents into prox and mid-portion shunt

4 surgical RVPAc replacements + PA’s ballooning
Shunt-related reinterventions

R RVPA c [n=6]

6 cath - based interventions

- 2 stent into mid-portion shunt
- 2 stents into prox shunt
- 2 balloon plastic of PA’s
- 1 surgical PA’s reconstruction
Patients characteristics at hemi-Fontan procedure

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Left RVPAc (n=25)</th>
<th>Right RVPAc (n=21)</th>
<th>Right reinforced RVPAc (n=38)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [months]</td>
<td>6.4±1.7</td>
<td>6.2±1.9</td>
<td>5.9±2.0</td>
<td>NS</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>6.3±0.99</td>
<td>6.2±0.82</td>
<td>6.2±0.89</td>
<td>NS</td>
</tr>
<tr>
<td>Systemic sat.[%]</td>
<td>72.2</td>
<td>73.7</td>
<td>75.1</td>
<td>NS</td>
</tr>
<tr>
<td>RV dysfunction</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>NS</td>
</tr>
<tr>
<td>Additional procedures</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>NS</td>
</tr>
<tr>
<td>Mortality rate</td>
<td>1/25</td>
<td>1/21</td>
<td>0/38</td>
<td>NS</td>
</tr>
<tr>
<td>CPB time [min.]</td>
<td>106±32</td>
<td>98±41</td>
<td>94±37</td>
<td>0.02</td>
</tr>
<tr>
<td>Mean DHCA [min.]</td>
<td>42±9</td>
<td>33, 37, 31*</td>
<td>0</td>
<td>waived</td>
</tr>
</tbody>
</table>
## Follow up

<table>
<thead>
<tr>
<th>Parameter</th>
<th>L-RVPAc</th>
<th>R RVPAc</th>
<th>RR RVPAc</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early mortality rate</td>
<td>3/32</td>
<td>4/28</td>
<td>3/41</td>
<td>NS</td>
</tr>
<tr>
<td>Interim mortality</td>
<td>1/29</td>
<td>1/24</td>
<td>0/38</td>
<td>NS</td>
</tr>
<tr>
<td>Lost follow up</td>
<td>3/28*</td>
<td>2/24*</td>
<td>0/38</td>
<td>NS</td>
</tr>
<tr>
<td>Mortality at hemi-Fontan</td>
<td>1/25</td>
<td>1/21</td>
<td>0/38</td>
<td>NS</td>
</tr>
</tbody>
</table>

* went to another hospital

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Conclusions

• The strategy of using right reinforced RVPAc with the modified “dunk” technique and direct distal anastomosis during the Norwood procedures for HLHS significantly reduces the number of catheter-based unintended shunt-related interventions during the inter-stage period.

• This strategy allows for a more homogenous development of pulmonary arteries before the second, surgical stage.
Future directions

• Assessment of pulmonary arteries development before Fontan completion
• Assessment of RV function before Fontan completion
• Assessment of RVPAc removal on RV (regional) function
• Modification of shape and diameter of RR RVPAc
Welcome to Krakow, Poland
The „morning-after” syndrome
### Table 3. Studies Comparing the Impact of the Classic and Modified Norwood Procedure on Growth and Development of Pulmonary Arteries

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Study Type</th>
<th>Level of Evidence</th>
<th>Number mBTS</th>
<th>Number RV-PA</th>
<th>Nakata Index, mm²/m² mBTS</th>
<th>Nakata Index, mm²/m² RV-PA</th>
<th>Central PA Stenosis mBTS</th>
<th>Central PA Stenosis RV-PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ohye et al.²⁶,a</td>
<td>2010</td>
<td>RCT</td>
<td>Level 1b</td>
<td>159</td>
<td>191</td>
<td>169 (P = .009)</td>
<td>145</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Pruetz et al.²⁸,b</td>
<td>2009</td>
<td>RCS</td>
<td>Level 2b</td>
<td>103</td>
<td>56</td>
<td>169 (P = .004)</td>
<td>212</td>
<td>14/32</td>
<td>25/32</td>
</tr>
<tr>
<td>Caspi et al.²⁹,c</td>
<td>2008</td>
<td>RCS</td>
<td>Level 2b</td>
<td>19</td>
<td>23</td>
<td>192 (P = .03)</td>
<td>238</td>
<td>0</td>
<td>1/23</td>
</tr>
<tr>
<td>Nakano et al.³⁰,d</td>
<td>2008</td>
<td>RCS</td>
<td>Level 2b</td>
<td>12</td>
<td>31</td>
<td>162 (P = .22)</td>
<td>191.5</td>
<td>4/12</td>
<td>18/31</td>
</tr>
<tr>
<td>Graham et al.³¹,e</td>
<td>2007</td>
<td>RCS</td>
<td>Level 2b</td>
<td>35</td>
<td>41</td>
<td>188 (P = .009)</td>
<td>270</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Griselli et al.³²,f</td>
<td>2006</td>
<td>RCS</td>
<td>Level 2b</td>
<td>177</td>
<td>49</td>
<td>NA</td>
<td>NA</td>
<td>50/177</td>
<td>47/49</td>
</tr>
<tr>
<td>Rumble et al.³³,g</td>
<td>2005</td>
<td>RCS</td>
<td>Level 2b</td>
<td>18</td>
<td>12</td>
<td>156 (P &gt; .05)</td>
<td>204</td>
<td>14/18</td>
<td>10/12</td>
</tr>
<tr>
<td>Januszewska et al.³⁴,h</td>
<td>2005</td>
<td>RCS</td>
<td>Level 2b</td>
<td>27</td>
<td>51</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Maher et al.³⁵,i</td>
<td>2003</td>
<td>LCS</td>
<td>Level 2b</td>
<td>10</td>
<td>14</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

* mBTS, modified Blalock-Taussig shunt; NA, not available; PA, pulmonary artery; RCS, retrospective cohort series; RCT, randomized controlled trial; RV-PA, right ventricle to pulmonary artery conduit.

1. Diameter of distal left PA (mBTS vs RV-PA, P = .54); diameter of distal right PA (mBTS vs RV-PA, P = .54).
2. Sixty-four patients (32 from each group) underwent pre-Glenn catheterizations, and angiograms were used to measure pulmonary artery size. RV-PA vs mBTS right pulmonary artery/left pulmonary artery ratio = 1.02 vs 1.39; P = .001. RV-PA vs mBTS left pulmonary artery size = 29 vs 19 mm²; P = .001.
3. Significantly lower left to right pulmonary artery ratio (P = .02). A left to right pulmonary artery ratio of 0.5 or less was found in 4 patients (21%) in the Blalock-Taussig (BT) group compared with none in the RV-PA conduit group (P < .01).
4. Freedom from PA plasty was significantly lower in the RV-PA conduit group than in the mBTS group (63.5% vs 31.1% at 5 years; P = .034). Post-Fontan PA index was similar for the 2 groups (194.0 ± 58.4 mm²/m²).
5. Similar need for PA augmentation at the time of second stage.
6. Actuarial freedom from reoperation was 60% ± 3%, 52% ± 4%, and 50% ± 4% at 1, 5, and 10 years, respectively.
7. For the RV-PA conduit group, the maximum indexed left PA and right PA diameters were comparable (P = 1.00), whereas in the classical group, the maximum indexed left PA diameter was generally smaller than the maximum indexed right PA diameter (P < .05).
8. Patients with the RV-PA conduit had a larger right (P = .001) and left (P = .006) PA index.
9. The patients in the RV-PA conduit group had a higher ratio of pulmonary artery to aorta diameter (1.51 ± 0.006 vs 1.37 ± 0.1).