Pressure volume relations obtained by 3D-real-time echocardiography and mini-pressure wire - multimodal validation-studies with MRI and conductance-catheter in piglets

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Pressure-Volume Relation

Pressure-Volume-Relation (PVR)

- systol. und diastol. function
- work load
- ventriculo-arterial coupling
- quantification of interventions
  - medical
  - caths
  - operations
Introduction

Gold Standard Conductance-Technology

Disadvantage:
- Calibration with a 2nd method
- >= 5F sheath
- additional radiation
  ⇒ limited use in small children

Less invasive, alternative technique in small hearts?
3D-Volumetry

Volume-Time-Curve

3D-Echocardiography
Instantaneous Pressure

Mini pressure wire with micromanometer

Mini-Pressure wire 0.014``
RADl, St. Jude

Online pressure time curves
3DE-derived PVR

- 3DE: Volume-time curve
- Synchronization 5ms (Herberg et al, 2013)
- 3D-derived PV-loop

simultaneously pressure-time curve
Aim & Methods

**Volumetry:**  \(\rightarrow\) 3DE vs CMR

Accuracy of 3DE **volume measurements** in small hearts vs CMR as gold standard for volume analysis

**Pressure Volume Analysis:**  \(\rightarrow\) 3DE vs Conductance

Validation of **accuracy and reliability** of PVR obtained by 3D-echocardiography & mini pressure wire vs gold standard conductance-technology

using identical anesthesia, animal preparation & monitoring
Volumetry 3DE vs CMR

8 piglets  
weight 5.5kg ± 0.54  
BSA 0.32 ± 0.03 m²

3D-Echocardiography
Philips IE 33, X7-2  
Full Volume Datasets using 4 cardiac cycles  
Volume rate 35-50/s

Analysis:
LV QLab Adv 7.0 und 8.1  
RV TomTec RV Fct 1.1

CMR
3 Tesla Ingenia, Philips  
1.25mmx1.25mm mit 4mm slice thickness  
Frame rate 50/s

Analysis:
View Forum Philips  
LV – short axis  
RV – axial cine
Comparison 3DE – CMR
Bland-Altman-Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CMR vrs 3D</th>
<th>Bias 95% Limits of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LV</td>
<td>RV</td>
</tr>
<tr>
<td>EDV [ml]</td>
<td>-0.03</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>[-1.2; 1.1]</td>
<td>[-3.1;3.1]</td>
</tr>
<tr>
<td>ESV [ml]</td>
<td>-0.12</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>[-1.1; 0.9]</td>
<td>[-3.1; 1.9]</td>
</tr>
<tr>
<td>SV [ml]</td>
<td>-0.01</td>
<td>0.57</td>
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<tr>
<td></td>
<td>[-2.4; 2.2]</td>
<td>[-0.7; 1.9]</td>
</tr>
<tr>
<td>EF %</td>
<td>2.71</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>[-5.6; 11.0]</td>
<td>[-8.0; 18.9]</td>
</tr>
</tbody>
</table>
Volume-Time-Curves
Pressure-Volume-Relation

❤ 20 Piglets

Weight: 6.17 [3.6-8.0] kg  
BSA 0.34 [0.24-0.41] m²

❤ Simultaneous comparison of PVR

• 3D + mini-pressure-wire
• conductance technology

❤ various pharmacologic conditions

• Baseline
• Phenylephrin  10-40µg/kg/min
• Esmolol  1mg/kg
Pressure-Volume-Relation

Parameter:

<table>
<thead>
<tr>
<th>Systolic Function</th>
<th>Equation</th>
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<tbody>
<tr>
<td>dp/dt max – maximal rate of pressure change over time</td>
<td></td>
</tr>
<tr>
<td>Ees</td>
<td>Endsystolic Elastance, “contractility”</td>
</tr>
<tr>
<td>Ea</td>
<td>Effective Arterial Elastance, “art. resistance”</td>
</tr>
<tr>
<td>Ees/Ea</td>
<td>ventriculoarterial coupling</td>
</tr>
</tbody>
</table>

\[1 \text{ single beat calculation} \text{ Ten Brinke, 2008 and 2010} \]

ESP=end systolic pressure
Systolic PVR under various conditions

3D-Echo (3D)-derived pressure-volume relations compared to parameters obtained by conductance technology (Cond) under various conditions (mean and 95% CI), n=16.

* = significant from baseline

Ees – load independent contractility; Ea – load independent vascular resistance
Systolic PVR under various conditions

3D-Echo (3D)-derived pressure-volume relations compared to parameters obtained by conductance technology (Cond) under various conditions (mean and 95% CI), n=16. * = significant from baseline

Baseline Ees 18-22 mmHg/ml; Phenyl Ees 27 mmHg/ml
Cassidy, 1997; Bakhtiary, 2007
**Parameter:**

**Diastolic Function**

\( \text{dp/dt min} \) - minimal rate of pressure change over time

\( \text{EDV}_{10} \) – EDV at a common enddiastolic pressure of 10 mmHg

\( \tau \) – isovolumic relaxation constant

\(^1\) Klotz, 2006 and 2007
Diastolic PVR under various conditions

3D-Echo (3D)-derived pressure-volume relations compared to parameters obtained by conductance technology (Cond) under various conditions (mean and 95% CI), n=16.

* = significant from baseline

Baseline dp/dt min 2200-2500 mmHg/s
Phenyle dp/dt min 2400mmHg/s
Cassidy, 1997; Klautz 1997
Comparison 3DE – Cond
Bland-Altman-Analysis

Intraobserver

<table>
<thead>
<tr>
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<th>Variation Coefficient</th>
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<tbody>
<tr>
<td>Ees</td>
<td>2.79 ± 3.53</td>
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<tr>
<td>Ees/Ea</td>
<td>3.07 ± 3.60</td>
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<tr>
<td>Tau</td>
<td>0.07 ± 0.16</td>
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<tr>
<td>EDV10</td>
<td>2.55 ± 2.18</td>
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</table>

Interobserver

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<th>Variation Coefficient</th>
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<tr>
<td>Ees</td>
<td>2.61 ± 3.34</td>
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<tr>
<td>Ees/Ea</td>
<td>2.83 ± 3.49</td>
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<tr>
<td>Tau</td>
<td>0.75 ± 1.42</td>
</tr>
<tr>
<td>EDV10</td>
<td>1.2 ± 0.79</td>
</tr>
</tbody>
</table>

Intra- and Interobserver variation < 10%
Conclusion I

**3DE volume calculations in small hearts**
- good agreement to CMR
- volume changes over time are comparable to CMR

**PVR generated by 3DE & pressure wire**
- good agreement to results obtained by the gold standard conductance technology
- feasible and reliable to assess different conditions of cardiac function in small hearts
Conclusion II

• Limitations
  • Single beat algorithms

• Less invasive

• applicable in neonates and small children (Herberg, Gatzweiler et al, 2013)
Thank you for your attention

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Statistics
Eva Gatzweiler

Deutsche Herzstiftung
Ventricular pressure–volume loops obtained by 3D real-time echocardiography and mini pressure wire—a feasibility study

Ulrike Herberg · Eva Gatzweiler · Thomas Breuer · Johannes Breuer

PVR obtained by

3DE + simultaneous pressure measurements

using a mini pressure wire

is feasible and reproducible
Ventricular pressure–volume loops obtained by 3D real-time echocardiography and mini pressure wire—a feasibility study

Ulrike Herberg · Eva Gatzweiler · Thomas Breuer · Johannes Breuer

N=31

| Alter       | 3 Tage - 22,7 Jahre  
|-------------|----------------------
|             | Median 1,8 Jahre     |
| Gewicht     | 2,8 - 80 kg         
|             | Median 11 kg         |
Ventricular pressure–volume loops obtained by 3D real-time echocardiography and mini pressure wire—a feasibility study

Ulrike Herberg · Eva Gatzweiler · Thomas Breuer · Johannes Breuer