Emboli Production in Hardshell Venous Reservoirs at Low Reservoir Levels

Devin Eilers, BS, Willie Glaze, BS, & David Holt, MA, CCT
Clinical Perfusion Education
Objectives

• Hypothesis/Research Question
• Clinical Significance
• Circuit Design
  – Venous Reservoirs
• Setup Protocol
• Data Collection
• Results
Hypothesis and Research Question

From studies we pieced together our hypothesis

– **Research question**: What is the effect of flow and reservoir level on gaseous microemboli production in the venous reservoir?

– **Hypothesis**: Emboli production in the venous reservoir will increase with increasing flow and decreasing reservoir level.

– **Null hypothesis**: Emboli production in the venous reservoir will not increase with increasing flow or decreasing reservoir level.
Clinical Significance

Currently each reservoir is assigned a manufacturer’s recommended safe operating level

– But they do not specify what the maximum safe flow is at that minimum operating level.

– For today’s reservoirs is there a common relationship between emboli production, flow, and reservoir level.
Circuit Design

The circuit will consist of the following components in order:

1. Venous Reservoir
2. Sarns 9000 roller pump
3. Oxygenator with integrated arterial line filter
4. Deoxygenator/Bubble trap

EDAC measurements:
- Pre-venous reservoir
- Post venous reservoir
- Post arterial line filter
Venous Reservoirs

Sorin Synthesis R reservoir
- Minimum reservoir level 300 mL
- Maximum flow 8 L/min
- Angled blood outlet

Terumo Capiox HSVR
- Minimum reservoir level 200 mL
- Maximum flow 7 L/min
- Vertical blood outlet

Medtronic Affinity Fusion Reservoir
- Minimum reservoir level 200 mL
- Maximum flow 7 L/min
- Vertical blood outlet
Deoxygenator

- Terumo Capiox SX10 Oxygenator
- Procedure outlined by Dunningham et al.
  - Mixed CO₂ and room air using 2 roller pumps
  - Blood:deoxygenator = 1:1.20-1.25
  - FiCO₂ 20-25%
Setup Protocol

• We reused the same tubing for each of the trials
  – Allowed the EDAC sensors to be in the exact same location
  – This allowed the tubing to have the same mechanical motion
Setup Protocol

The circuit would be primed with saline
- The volume would be estimated
- The HCT of the bovine blood was measured
- The bovine blood was diluted with saline for a HCT between 22% and 23%

Volume desired\(\times desiredHCT = \frac{(preHCT\times bloodVol)}{(bloodVol+primeVol+salineVol)}\)  
[Solve for saline volume]
Data Collection

- The EDAC was found to have limitations when flow exceeded 3 L/min
- The flows examined are 1, 2, and 3 L/min
- The reservoir levels studied are 600, 500, 400, 300, 200, and 100 mL
Sorin Synthesis R
### Sorin Phisio – Flow

<table>
<thead>
<tr>
<th>Overall linear trend</th>
<th>1 vs. 2</th>
<th>2 vs. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 vs. 200</td>
<td>0.390</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>200 vs. 300</td>
<td>0.749</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>300 vs. 400</td>
<td>0.725</td>
<td>0.022</td>
</tr>
<tr>
<td>400 vs. 500</td>
<td>1.000</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>500 vs. 600</td>
<td>0.982</td>
<td></td>
</tr>
</tbody>
</table>

### Sorin Phisio – Level

<table>
<thead>
<tr>
<th>Overall linear trend</th>
<th>Level (mL)</th>
<th>Average percent increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 vs. 200</td>
<td>600-500</td>
<td>-3.33%</td>
</tr>
<tr>
<td>200 vs. 300</td>
<td>500-400</td>
<td>0.53%</td>
</tr>
<tr>
<td>300 vs. 400</td>
<td>400-300</td>
<td>34.58%</td>
</tr>
<tr>
<td>400 vs. 500</td>
<td>300-200</td>
<td>34.18%</td>
</tr>
<tr>
<td>500 vs. 600</td>
<td>200-100</td>
<td>29.97%</td>
</tr>
</tbody>
</table>
SORIN SYNTHESIS R HSVR

- Post reservoir 1 L/min
- Post reservoir 2 L/min
- Post Reservoir 3 L/min
- Linear (Post reservoir 2 L/min)
- Linear (Post Reservoir 3 L/min)

SORIN SYNTHESIS R HSVR

- 600 mL level
- 500 mL level
- 400 mL level
- 300 mL level
- 200 mL level
- 100 mL level
- Linear (100 mL level)

Mathematical equations:
- \( y = 4153.2x + 11855 \) with \( R^2 = 0.9311 \)
- \( y = 1497.8x + 22.467 \) with \( R^2 = 0.6915 \)
- \( y = 17372x - 16735 \)
Terumo Capiox
### Terumo Capiox HSVR

<table>
<thead>
<tr>
<th>Level (mL)</th>
<th>Average Percent Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>600-500</td>
<td>50.32%</td>
</tr>
<tr>
<td>500-400</td>
<td>9.22%</td>
</tr>
<tr>
<td>400-300</td>
<td>3.25%</td>
</tr>
<tr>
<td>300-200</td>
<td>-3.78%</td>
</tr>
<tr>
<td>200-100</td>
<td>26.30%</td>
</tr>
</tbody>
</table>

### Terumo Capiox FX25 – Flow

<table>
<thead>
<tr>
<th>Overall linear trend</th>
<th>1 vs. 2</th>
<th>2 vs. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

### Terumo Capiox FX25 – Level

<table>
<thead>
<tr>
<th>Overall linear trend</th>
<th>100 vs. 200</th>
<th>200 vs. 300</th>
<th>300 vs. 400</th>
<th>400 vs. 500</th>
<th>500 vs. 600</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.001</td>
<td>0.608</td>
<td>1.000</td>
<td>0.902</td>
<td>0.973</td>
<td>0.100</td>
</tr>
</tbody>
</table>
Medtronic Affinity

Medtronic Affinity HSVR

FLOW (L/MIN)

EMBOLIC COUNT

LEVEL (ML)

Post reservoir mean 1 L/min
Post reservoir mean 2 L/min
Post reservoir mean 3 L/min

0-500 500-1000 1000-1500 1500-2000 2000-2500 2500-3000
### Medtronic Affinity HSVR

<table>
<thead>
<tr>
<th>Medtronic Affinity – Flow</th>
<th>Overall linear trend</th>
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</thead>
<tbody>
<tr>
<td>[Data Table]</td>
<td>&lt;0.001</td>
</tr>
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<td>1 vs. 2</td>
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<tr>
<td>[Data Table]</td>
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</tr>
<tr>
<td>100 vs. 200</td>
<td>0.897</td>
</tr>
<tr>
<td>200 vs. 300</td>
<td>0.969</td>
</tr>
<tr>
<td>300 vs. 400</td>
<td>1.000</td>
</tr>
<tr>
<td>400 vs. 500</td>
<td>0.840</td>
</tr>
<tr>
<td>500 vs. 600</td>
<td>0.831</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level (mL)</th>
<th>Average Percent Increase</th>
</tr>
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<tbody>
<tr>
<td>600-500</td>
<td>20.22%</td>
</tr>
<tr>
<td>500-400</td>
<td>14.82%</td>
</tr>
<tr>
<td>400-300</td>
<td>2.16%</td>
</tr>
<tr>
<td>300-200</td>
<td>17.54%</td>
</tr>
<tr>
<td>200-100</td>
<td>22.97%</td>
</tr>
</tbody>
</table>
ANOVA using Scheffe’s method for multiple comparisons

<table>
<thead>
<tr>
<th>Reservoir Type</th>
<th>Overall ANOVA test of differences</th>
<th>&lt;0.001</th>
<th>Medtronic Affinity vs. Sorin PHISIO</th>
<th>&lt;0.001</th>
<th>Medtronic Affinity vs. Terumo Capiox</th>
<th>&lt;0.001</th>
<th>Sorin PHISIO vs. Terumo Capiox</th>
<th>&lt;0.001</th>
</tr>
</thead>
</table>


Evaluation of emboli pre ALF compared to post ALF

• Our study examined the amount of emboli produced in the venous reservoir.

• We wanted to test the statistical significance of the amount of emboli produced in the venous reservoir to the emboli that went through the arterial line filter (ALF) to the patient.

• There was a strong linear correlation between the number of bubbles going into the ALF and the number coming out.

• The Pearson coefficient is 0.892 (p<0.001) this represents the linear correlation between 2 variables.
  – A perfect positive correlation would return a Pearson coefficient of +1.
<table>
<thead>
<tr>
<th>Measure</th>
<th>Median</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post ALF count / Pre ALF count</td>
<td>0.013</td>
<td>0.002 – 0.028</td>
</tr>
<tr>
<td>Post ALF volume / Pre ALF volume</td>
<td>0.010</td>
<td>0.001 – 0.020</td>
</tr>
</tbody>
</table>
Conclusion

- The only surface for a bubble to dissipate due to the effects of buoyancy in an open circuit is in the HSVR.
- The purpose of this study was to show that all reservoirs showed this trend of increasing GME production at low levels and varying flow.
- This study demonstrates a perfusion best practice should be adopted that flow should be attenuated as the reservoir level decreases.
Special Thanks To:

- Willie Glaze
- David Holt
- Sue Stewart
- Harlan Sayles
References


References


9. Hileman, R.E., Wall, B.,


