Pulse Generation During Cardiopulmonary Bypass

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Abstract

This study shows that cannula rigidity is a major contributor to adequate pulse generation during pulsatile bypass flow. In addition, there is a discussion of the analysis which led the authors to conclude that poor pulse generation was related to cannula, and a study of the level of hemolysis induced by the Cobe/Stockert pulsatile generator.

Introduction

In this report is a brief look at one of the requirements for use of a new pulsatile flow generator. As a result of this study, the authors gained a better understanding of the requirements for pulse generation. Pulse generation was heretofore assumed by the authors to be a function of the pulsatile generator alone. Therefore, in order to produce better pulsation, alteration of the generator was required. However, in our experiments, it was clearly shown that the cannula is a major contributor to adequate pulse generation. While it is still true that the generator must have the capacity to produce the desired pulse, it was determined that the cannula rigidity was also a primary factor. The cannula rigidity, in terms of deformation or expansion due to line pressure, was shown to have significant effect on the level of pulse transmitted to the patient’s arterial system. In addition, the hemolysis testing, performed as a part of this study, showed more blood damage occurs during pulsing with rigid cannula, as compared to that which occurs during pulsing with less rigid cannula, both being greater than that found with continuous flow pumping.

Materials and Methods

To determine the pulse generation capability of the new device,* the in vivo testing made use of a reservoir,** recirculation loop with cannula, roller pump and pulsatile controller. The pulsatile controller generated pulses by varying the speed and duration of the pump cycle. Flow rate was measured using an electromagnetic flowmeter*** and pressure was measured by the use of transducers. Both flow rate and pressure were recorded simultaneously upon a strip chart recorder,**** utilizing light pen deflection for maximum response.

In vivo testing utilized the same measuring techniques in conjunction with a 35+40 kilogram dog anesthetized with either pentobarbitol or ketamine. The animal was heparinized with 300 units/kilogram and maintained with activated clotting time in excess of 600 seconds. A sternotomy was performed and cannulation was accomplished with two venous cannulae and one aortic cannula. All cannulae were straight, as opposed to the curved design, and fabricated of polyvinyl chloride. Additional pressure measurements were made at the femoral artery, aortic arch and left atrium.

* Cobe/Stockert, Model number 043021000, Cobe Laboratories, Inc., Lakewood, Colorado.
** SciMed, Model number RV1300-1, Minneapolis, Minnesota.
*** Gould Statham, Model number SP7519/2201, Oxnard, California.
**** Bell and Howell, Model number 5-164, Pasadena, California.
FIGURE 1. Peak Flow Rate Versus Peak Pressure. 22 French, 30%-50%-80% pulse time, 90 beats per minutes.

FIGURE 2. Peak Flow Rate Versus Peak Pressure. 22 French, 30%-50%-80% pulse time, 60 beats per minute.
FIGURE 3. Peak Flow Rate Versus Peak Pressure. 22 French, 30% pulse time, 60 and 90 beats per minute.

FIGURE 4. Peak Flow Rate Versus Peak Pressure. 22 French, 50% pulse time, 60 and 90 beats per minute.
FIGURE 5. Peak Flow Rate Versus Peak Pressure. 22 French, 80% pulse time, 60 and 90 beats per minute.

FIGURE 6. Peak Flow Rate Versus Peak Pressure. 16 French, 30%-50%-80% pulse time, 60 beats per minute.
FIGURE 7. Peak Flow Rate Versus Peak Pressure. 16 French, 80% pulse time, 60 and 90 beats per minute.

FIGURE 8. Peak Flow Rate Versus Peak Pressure. 16 French, 50% pulse time, 60 and 90 beats per minute.
FIGURE 9. Peak Flow Rate Versus Peak Pressure. 16 French, 50% pulse time, 60 and 90 beats per minute.

FIGURE 10. Peak Flow Rate Versus Peak Pressure. 16 French versus 22 French, 80% pulse time, 60 beats per minute.
Discussion and Results

During each of the in vitro tests performed on 12, 16, 20 and 22 French Bardic**** cannulae, a striking change occurred as the rate of pulsation (frequency) was increased. The frequency of pulsation was controlled by beat per minute settings on the pump controller, which varied the number of pulses supplied to the roller pump. All measurements began with an initial reading of 60 beats per minute with appropriate pump controller settings. As the frequency was increased from 60 to 90 beats per minute at flow rates of 2 liters per minute (Figure 3) the relationship of pre-cannula pressure to flow rate remained linear. The pressure resistance was slightly higher at the higher frequency. However, when the same change was made at 4 and 6 liters per minute (Figure 5), the relationship was noticeably nonlinear and the pre-cannula pressure fell off at the higher setting.

When the same relationship presented itself in the in vitro and in vivo studies, a thorough review of all strip chart data was made. This revealed that in all cases the flow rate increased without the expected increase in pressure. In reviewing the test data, a comparison of 16 French with 22 French data shows the 16 French pressure flow relationship remains linear through 6 liters per minute, while 22 French data remained linear through only 2 liters per minute (Figure 10). After thoroughly checking the data relating to the length and speed setting for the pumping cycle, no assignable cause relating to pump operation was detected. Our attention then turned to the delivery system from pump to patient. No variation or unusual tubing compliance was found. Measurement of the arterial cannula, however, revealed a constant wall thickness in both the 16 French and 22 French, with the diameter changing appreciably. The net result was a change in rigidity. Qualitative flexing of the cannula showed an appreciable difference from 16 French to 22 French.

**** United States Catheter and Instruments, Inc., Model number 1860, Murray Hill, New Jersey

HEMOLYSIS TEST DATA

I. Initial Evaluation

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<tr>
<th>Test</th>
<th>Flow Rate</th>
<th>Index of Hemolysis (gm/100 L)</th>
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<tbody>
<tr>
<td>A</td>
<td>4 LPM</td>
<td>.052</td>
</tr>
<tr>
<td>B</td>
<td>2.8 LPM</td>
<td>.048</td>
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</tbody>
</table>

Legend:

A = 90 beats per minute (BPM), 30% run time (RT), 6 liters per minute (LPM),
B = 90 beats per minute (BPM), 30% run time (RT), 6 liters per minute (LPM).

Test Conditions:

Hematocrit = 35%

1/2 inch ID pump header

II. Cannula Study

<table>
<thead>
<tr>
<th>Cannula</th>
<th>Time</th>
<th>Index of Hemolysis (gm/100 L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100 BPM/ 80 BPM/ 60 BPM/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7% HT BT 7% HT BT 5% HT BT</td>
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</table>

<table>
<thead>
<tr>
<th>Cannula</th>
<th>Time</th>
<th>Continuous</th>
<th>100 BPM/</th>
<th>80 BPM/</th>
<th>60 BPM/</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 Fr</td>
<td>30</td>
<td>7.6</td>
<td>24.3</td>
<td>20.3</td>
<td>20.8</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>15.6</td>
<td>33.7</td>
<td>21.1</td>
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<td></td>
<td>120</td>
<td>34.1</td>
<td>33.2</td>
<td>33.2</td>
<td>33.2</td>
</tr>
<tr>
<td>16 Fr</td>
<td>30</td>
<td>.041</td>
<td>.106</td>
<td>.139</td>
<td>.046</td>
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<td>22 Fr</td>
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<td>.079</td>
<td>.166</td>
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<td>.088</td>
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</tbody>
</table>

Test Conditions for Cannula Study:

Hematocrit = 35%

Flow Rate = 4 liters per minute
1/2 inch ID pump header

FIGURE 12. Hemolysis Test Data.
No other significant observations were made relative to the pump to patient system.

Hemolysis testing was then performed in vitro, utilizing the same measuring techniques as for pressure flow and an otolidine dihydrochloride analysis for plasma hemoglobin. Testing was performed at 4 liters per minute only, and the level of hemolysis varied with the cannula size used. We evaluated 12, 16, 20 and 22 French cannula (Figure 12). Four pump circuits and one static control were used for each test, allowing us to gather data at 60, 80 and 100 beats per minute, as compared to continuous flow under the same conditions. The level of hemolysis encountered with pulsatile flow was highest with the 12 French cannula, index of hemolysis greater than 7.0 grams/100 liters, and decreased as cannula size increased. In areas of highest hemolysis, we also find the best pulse generation. This is thought to be due to the high velocities (greater than 1000 centimeters per second) encountered in these areas. Overall, the data was similar to the continuous flow pump control for larger cannula, but was greater than the continuous flow pump control for smaller cannula sizes.

Conclusions

Cannula rigidity is an important consideration when contemplating pulsatile flow, in order to achieve the desired pulse. Similar considerations should be given to cannula size and construction in order to minimize hemolysis. The choices of cannula size and rigidity should be made in light of the amount of pulsation required and hemolysis that will be encountered. As rigidity increases, so does the attainable pulse level. However, reducing cannula size to gain rigidity may increase the hemolysis encountered during bypass. This would indicate that metal cannula with similar internal diameter and surface characteristics would yield the optimum in pulse generation. This indication, however, awaits further study before it can be reasonably concluded.

References