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Original Articles

Safety Testing of Left Ventricular Vent Valves

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Abstract: Vent vacuum relief valves (VRVs) are used to limit the negative pressure at the ventricular vent catheter tip as well as prevent reversal of blood flow and prevention of air embolism. The purpose of this study was to evaluate the performance of three commercially available ventricular vent valves. The negative pressure at which the vent valve opened was measured at the valve inlet using high-fidelity pressure transducers. Also, the flow rate at which air entrainment occurred due to valve opening was recorded. Using a 51.5 cm column of saline, the resistance for each valve was calculated. The mean ± SD opening negative pressures were –231.3 ± 35.2 mmHg for the Quest Medical valve, –219.8 mmHg ± 17.2 for the Sorin valve, and –329.6 ± 38.0 mmHg for the Terumo valve. The red Quest Medical valve opened at a lower flow (1.44 ± .03 L/min) than the dark blue Sorin valve (2.93 ± .01 L/min) and light blue LH130 Terumo valve (2.36 ± .02 L/min). The Sorin valve had the least resistance of 34.1 dyn·s/cm^5, followed by the Terumo LH130 valve resistance of 58.1 dyn·s/cm^5, and the Quest Medical VRV-II valve with a resistance of 66.5 dyn·s/cm^5. We found that the valves are significantly different in the negative pressure generated. Understanding the limitations of these devices is important to reduce the occurrence of adverse events associated with venting and to select the best device for a specific clinical application. **Keywords:** one-way valve, check relief valve, vacuum relief valve, cardiopulmonary, sucker, left ventricular vent. *JECT. 2015;47:29–31*

Venting the left ventricle is an essential part of many cardiac surgical procedures to prevent ventricular distension while enhancing surgical exposure. Vent catheter designs were first evaluated by Marco in 1977 (1), who quantified the percentage of cardiac output removed by the vent catheters and the hemolysis associated with high flow rates. They also evaluated the ability of various catheter designs to remove air from the left ventricle.

Adverse events can occur with the use of a left ventricular vent. Excessive suction can cause injury to the endothelium, but the greatest danger is the risk of massive air embolism. This can occur due to vent suction tubing loaded in the roller pump in the reverse direction. Another potential cause of air embolism related to ventricular venting is positive pressure generated from suction lines into an unvented reservoir, causing air to travel backward through a non-occlusive vent roller pump (2–5).

Use of a one-way vacuum relief valve (VRV) can prevent reversal of flow and limit the amount of negative pressure in the vent line, thereby reducing the risk of air embolism and tissue injury. In recognition of the importance of this critical safety device, the American Society of ExtraCorporeal Technology Standards and Guidelines For Perfusion Practice (11/08/2013) includes Standard 6.6, which states that "A one-way valve in the vent line shall be employed during CPB procedures" (6).

Evaluation of VRV valves was first reported by Lewis in 1990 (7). They reviewed the level of suction at various flow rates and tested the valves for the presence of air leakage during reversed flow conditions. Since the last study was published 25 years ago, the purpose of this study was to evaluate currently available VRV valves.

MATERIALS AND METHODS

Three commercially available VRV valves (Figure 1), dark blue vacuum relief check valve (Sorin, Arvada, CO),

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Figure 1. Three vent valves tested.

red VRV-II (Quest Medical, Allen, TX), and light blue LH130 vent valve (Terumo Cardiovascular, Ann Arbor, MI), were compared in their ability to limit the amount of vacuum upstream of the valve, and their maximum flow and resistance. The test circuit consisted of a Sarns 8000 cardiopulmonary bypass console (Terumo Cardiovascular), a cardiotomy reservoir (Haemonetics, Braintree, MA), and the three types of VRV valves in parallel. High-fidelity AST 4000 pressure transducers (American Sensor Technologies, Mt. Olive, NJ) were between the VRV valves and the pump to measure negative pressure (Figure 2).

The flow at which the VRV opened to air was tested by isolating a valve in the circuit and increasing the roller head speed in 100 mL increments every 5 seconds until air was visibly detected. The negative pressure was noted at the point of air entrainment.

The resistance was calculated using a 1 L bag of .9% saline solution spiked with ¼ inch tubing with a valve at the distal end. Using Poiseuille's law where flow is equal to the change in pressure divided by the resistance, the flow rate under constant pressure would be proportional to the resistance produced by each valve. Using a 51.5 cm column of saline solution, a static fluid pressure of 38.71 dynes/cm^2 was generated. This pressure was calculated using the equation $P_{\text{static fluid}} = \rho g h$. This was calculated from the density of saline (1.02 g/cm^3), times the acceleration of gravity (980 cm/sec^2), multiplied by the height of the column (51.5 cm), and converted into pressure units, dynes/cm^2 (1 mmHg = 1330 dynes/cm^2). The flow rate was determined from the collecting fluid in the reservoir for 10 seconds. The saline solution was returned to the bag to maintain a constant static fluid level for each test.

Figure 2. Pressure and flow testing setup.

Statistical Analysis

SPSS was used for data analysis of significance. The results for negative pressure were not normally distributed and a Kruskal–Wallis test was used to determine if there was a significant difference, and a Wilcoxon signed-rank test was used to determine significant differences between the three groups. Results for flow rate and resistance were normally distributed and a one-way analysis of variance was used.

RESULTS

Data from three VRV valves were analyzed, $n = 4$ in each group, and the tests for each of the VRV valve were repeated. The red Quest Medical valve opened at a lower flow (1.44 ± .03 L/min) than the dark blue Sorin valve (2.93 ± .01 L/min) and light blue LH130 Terumo valve (2.36 ± .02 L/min) (Figure 3). Negative pressure at which the vent line on the valve opens was significantly different between the Terumo valve and the other valves, but no significant difference was found between the Quest Medical and Sorin valves. Results show mean negative pressures of –231.3 ± 35.2 mmHg for the Quest Medical valve, –219.8 ± 17.2 mmHg for the Sorin valve, and –329.6 ± 38.0 mmHg for the Terumo valve (Figure 4).

There was also a significant difference ($p < .05$) among all the three valves in reference to resistance. The Sorin

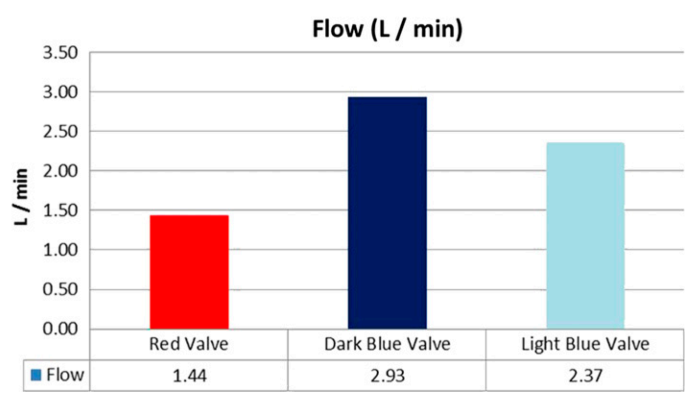

Figure 3. Flow comparison of vent valves.

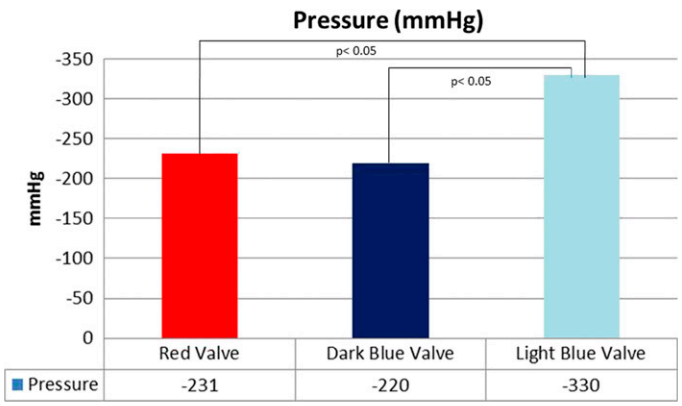

Figure 4. Negative pressure comparison of vent valves.

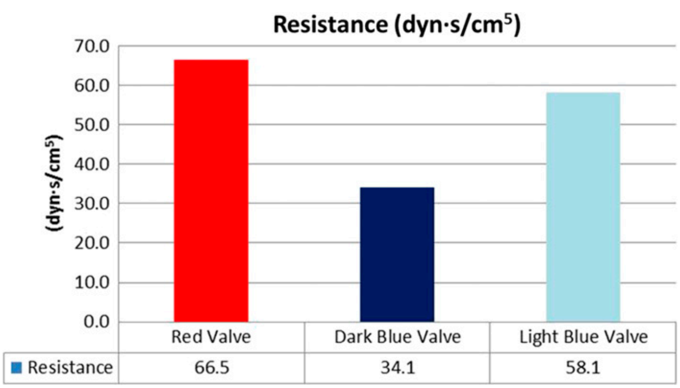

Figure 5. Resistance comparison of vent valves.

valve had the least resistance of 34.1 dyn·s/cm^5, the Terumo LH130 valve followed with a mean of 58.1 dyn·s/cm^5, and the highest resistance was the Quest Medical VRV-II valve with 66.5 dyn·s/cm^5 (Figure 5).

DISCUSSION

The desirable operational qualities of a vent valve are high flow capability, low shear stress on the blood components, and limited negative pressure to minimize tissue entrapment. Our study has found that there is a large variation in the operational characteristic among the three commercially available ventricular vent valves.

The perfusionist must know the range of operation and limitations of all the devices included in the extracorporeal circuit. Furthermore, it must be determined whether these components are safe for the circumstances anticipated to be encountered for a given surgical procedure. It was not the purpose of this paper to determine if one valve was better than another because this is only possible when applied to a particular clinical application. For example, a low negative pressure relief valve would be safer in systems where the aortic root vent and the cardioplegia line are connected to a Y-type adapter. In this configuration, excessive negative pressures may produce gaseous emboli through cavitation in the stagnant fluid in the cardioplegia line. If not diagnosed and removed prior to cardioplegia delivery, gaseous emboli may be introduced into the aorta root and potentially into the coronary arteries.

With respect to the removal of volume, if the required flow rate for blood volume removal is above the maximum flow rate of the valve, then excess volume will accumulate at the surgical field or vascular beds.

One of the limitations of this study was that the model used to test the valves did not include the resistance added by the vent catheter or the aortic root needle. This will further limit the capacity of the vent system and should be taken into account when designing a vent circuit.

CONCLUSION

In summary, among the valves tested, we determined that the dark blue Sorin valve has the highest flow rate, lowest resistance, and lowest negative pressure among the three valves. We found that the valves are significantly different in how they operate and the choice of valve could potentially cause significant changes in the amount of negative pressures generated. Understanding the limitations of these devices is important to reduce the occurrence of adverse events associated with venting and to select the best device for a specific clinical application.

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