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Triboelectric Charging and Dissipation Characteristics of the Maquet Quadrox-D Membrane Oxygenator

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Abstract: Triboelectric charging is commonly detected during cardiopulmonary bypass in circuits using roller pumps and PVC tubing. Dissipation of this charging is needed to prevent a spontaneous discharge from occurring. We evaluated the ability of the Quadrox-D (Maquet) to effectively remove the electrostatic charge accumulation, with and without a heater/cooler connection (H/C). A Quadrox-D oxygenator was evaluated using a Stockert SIII pump head, Cincinnati subzero H/E, and a custom adult extracorporeal membrane oxygenation tubing pack with 1/2″ PVC raceway. The circuit was primed and evaluated for triboelectric accumulation with and without H/C use. The results showed a linear relationship between increasing pump flow and static charge build-up when an H/C was not applied. The calculated r^2 value was .95. Incorporation of the H/C effectively eliminated charge accumulation. Increasing pump speed increases the amount of static charge created without the use of an H/C. Incorporation of an H/C effectively eliminates charge build-up in the Quadrox-D and is recommended while priming the circuit.
Keywords: electrostatic discharge, triboelectric charge, PVC tubing, Quadrox-D oxygenator, extracorporeal membrane oxygenation. *JECT. 2009;41:105–109*

Triboelectric and piezoelectric properties can be detected during cardiopulmonary bypass (CPB) that uses roller pumps and induce an unexpected electrostatic discharge if not dissipated. Triboelectric charges are encountered when there is a transfer of electrons from one surface to another as the tubing in the roller head is compressed and released (1). Piezoelectric charges occur when the tubing is mechanically deformed along the metal roller head surface. This artifact may be observed on the ECG during bypass (2,3) and could be misinterpreted as ventricular fibrillation (4), placing the patient at risk for unnecessary medical management.

These static electric properties are eliminated when the CPB circuit is used in conjunction with a heater/cooler (H/C). The H/C is used a grounding device, dissipating any built up static charge through the water pathway that is created when it is attached to the circuit. Without the connection to the H/C, the pump can act as a capacitor, causing a static charge build-up that can be spontaneously released (5,6). The voltage dissipated can be so great that the dielectric strength of the fiber will be exceeded, creating a hole in the heat exchange fiber. This electrostatic event creates a leak across the fibers, causing the oxygenator to fail (5,7). Currently used heat exchange fibers, within the oxygenator, have a dielectric strength of 600–800 DC volts per 25 µm of material thickness. This results in a 2000 DC volts or greater discharge to breakdown the heat exchange material (8). The Quadrox-D oxygenator uses a polymethylpentene fiber, which consists of a single-compartment gas exchange chamber and integrated heat exchanger that are contained within the same shell (9,10). This type of fiber has a higher dielectric strength over conventional fibers and may help inhibit electrostatic accumulation.

The purpose of this experiment was to determine whether static charge is created during extracorporeal membrane oxygenation (ECMO) in the same manner that static charge is created during a conventional CPB. It is expected that a similar charge will be generated during ECMO as is seen during CPB, because the same circuitry is used on the ECMO circuit. However, the charge build-up should not be as great in an ECMO circuit, compared with CPB, because there are no sucker or cardioplegia (CPS) lines. If the charge generated is large enough, a spontaneous static discharge may occur, and a fiber leak would be expected. Although not attaching water lines is uncommon in ECMO applications, there are still instances

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Table 1. Experimental group results.

Flow (L/min)	Trial 1 (DC Volts)	Trial 2 (DC Volts)	Trial 3 (DC Volts)	Trial 4 (DC Volts)	Trial 5 (DC Volts)	Average (All) (DC Volts)
1.0	430	450	450	410	450	438
2.0	900	900	860	890	900	890
3.0	1000	900	900	1000	900	940
4.0	1720	1760	1700	1700	900	1556
5.0	1440	1820	1780	1840	1650	1706
6.0	1940	1840	1800	2080	1800	1892

Documented electrostatic charge accumulation for each flow and trial conducted in the experimental group.
DC Volts, direct current volts.

in which the lines would not be attached immediately. Such applications include emergent set-up and initiation and oxygenator change out. This study will hopefully help determine the danger of running ECMO or CPB without water lines attached for a period of time.

MATERIALS AND METHODS

A custom adult ECMO circuit consisting of a Stöckert SIII pump head (Sorin Group, Milan, Italy), Quadrox-D oxygenator (Maquet, Bridgewater, NJ), custom adult ECMO tubing pack with PVC boot, incorporating a class VI medical grade ½ × 3/32″ untreated, shore grade 71 PVC tubing (Medtronic, Minneapolis, MN), and Cincinnati subzero H/C (Cincinnati, OH) was constructed. The pump was electrically grounded through an electrical outlet with no additional grounding source noted throughout the experiment. Prime consisted of 1 L Plasmalyte-A (Baxter Healthcare, Deerfield, IL), 44.6 mEq sodium bicarbonate, and 2000 units porcine heparin.

Static charge build-up on the adult ECMO circuit was determined through multiple trials by running the pump at varying speeds of 1–6 L/min. This was completed in a controlled environment in the operating room and was not attached to a patient. To test for static build-up in the experimental group, meaning the water lines of the H/C were not attached, the pump was turned on to 1 L/min and allowed to operate at that speed for 3 minutes. At the end of 3 minutes, an oscilloscope (Model 2260; Tektronix, Beaverton, OR) was used to measure and discharge the amount of static build-up that had accumulated in the time allotted. It was measured at the temperature probe inlet on the heat exchanger. Once recorded, the pump was turned to 2 L/min, and the procedure was repeated. This was completed to a flow of 6 L/min, and the entire experiment was repeated five times to ensure appropriate measurements had been obtained and were reproducible. Once complete, the experiment was repeated, but with the water lines attached, as a control group, to determine whether static build-up could be obtained at any flow. Results were recorded in the same manner discussed above. Relative humidity was recorded before the start of the experiment to document a constant controlled environment within the operating room.

RESULTS

The results collected for the experimental group indicated that increasing pump flows increased the amount of static build-up that is discharged. On average, voltage discharged at 6 L/min was more than four times higher than that at 1 L/min. The results signify a static build-up with a linear relationship resulting in an r^2 value of .95. This value is a statistical term that determines how well one result determines the other. In this case, the derived r^2 value between flow and static build-up is 0.95 and signifies that, if given a flow rate, the static build-up is 95% predicable. Tables 1 and 2 show the results obtained in each trial for the control and experimental groups. Figure 1A shows the results obtained in each trial completed for the

Table 2. Control group results.

Flow (L/min)	Trial 1 (DC Volts)	Trial 2 (DC Volts)	Trial 3 (DC Volts)	Trial 4 (DC Volts)	Trial 5 (DC Volts)	Average (All) (DC Volts)
1.0	0	0	0	0	0	0
2.0	0	0	0	0	0	0
3.0	0	0	0	0	0	0
4.0	0	0	0	0	0	0
5.0	0	0	0	0	0	0
6.0	0	0	0	0	0	0

Documented electrostatic charge accumulation for each flow and trial conducted in the control group.
DC Volts, direct current volts.

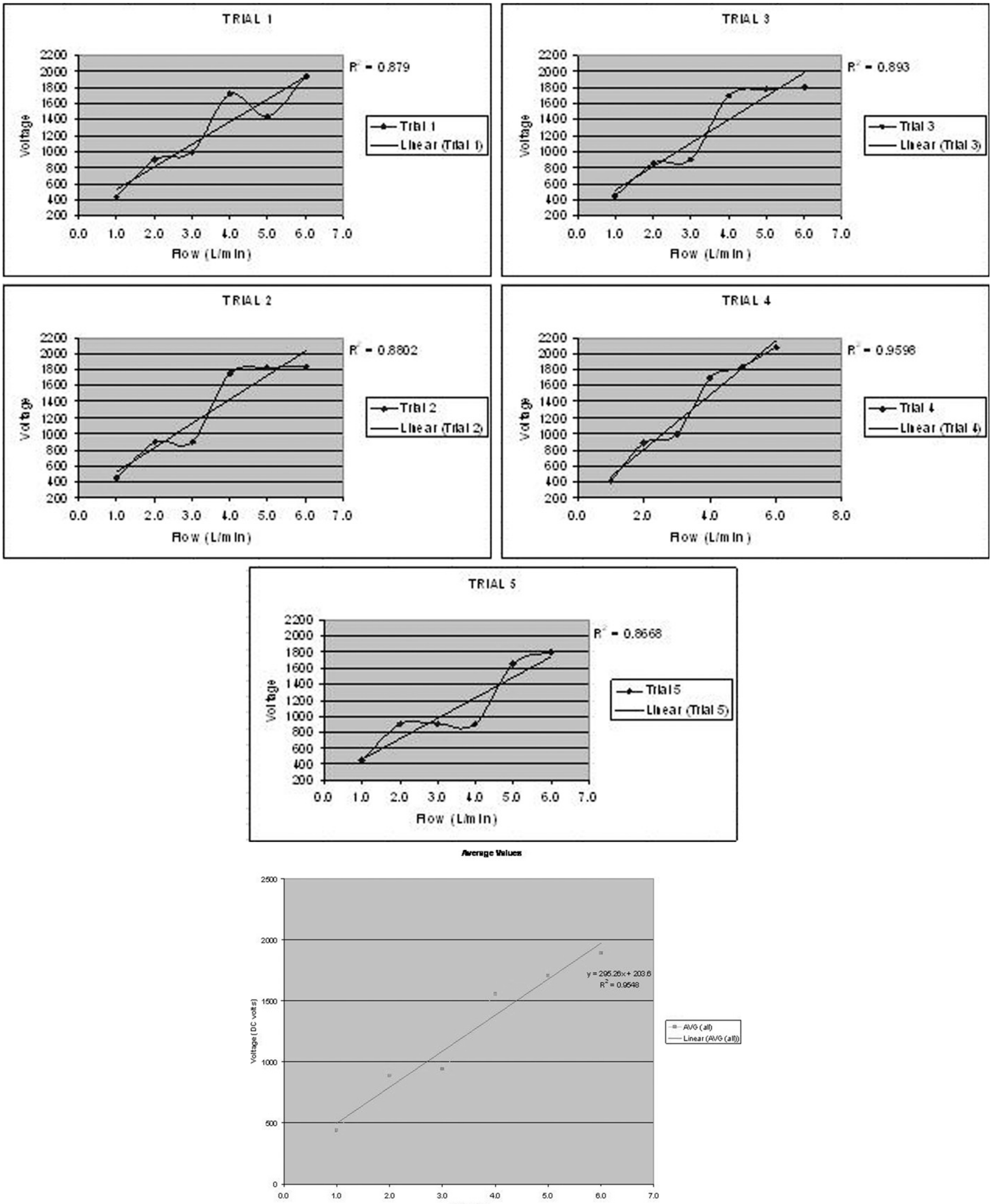

Figure 1. (A) Graphical representation of electrostatic charge accumulation for trials 1–5 of the experimental group. DC voltage, direct current volts. (B) Average electrostatic charge accumulation for each flow tested for the experimental group. DC voltage, direct current volts.

control and experimental groups. Figure 1B combines the information in Table 1 to obtain an average static charge build-up at each flow. Of note, as the control group, water lines of the H/C were attached, and the testing was repeated, which resulted in no charge accumulation at any flow. Also of note, no leaks were detected at the end of all testing.

To explain the different values recorded at different pump flows, an error in reading the oscilloscope may have occurred or the probe to measure the static discharge may have lost contact with the temperature probe inlet, causing the value to be higher or lower than normal. The trials were repeated multiple times in an attempt to validate the data.

Relative humidity also plays a role in charge generation. When relative humidity is 50–60%, it allows for rapid charge equalization between the pump rollers and tubing, alleviating charge build-up (3). Relative humidity for this experiment was 39–42%, measured by climate controls within the operating room suites, which is within the American Institute of Architects (AIA) Committee on Architecture for Health and the US Department of Health and Human Services recommendations of 30–60% (11). Relative humidity plays a role in the amount of static charge created, because a lower relative humidity value will increase the amount of charge created. This is because a lower relative humidity means the air is dryer. A higher relative humidity value will decrease the amount of charge generated for the opposite reason; there is more moisture in the air (1,12).

DISCUSSION

As documented in Table 1, a linear relationship exists between pump speed and charge generated, within the experimental group, when the circuit is not attached to the H/C. As the pump speed increases, so does the charge generated. For example, the charge generated at 6 L/min (1892 DC volts) is, on average, twice as much as the charge generated at 3 L/min (940 DC volts). Also, a large spike in generated voltage was observed when pump speed was increased from 3 to 4 L/min during testing.

This experiment, using a roller pump that was not connected to a H/C, showed the potential for unintended static charge build-up on ECMO with a recorded spontaneous discharge of >2000 DC volts within a 3-min time frame. That amount exceeds the dielectric strength of the heat exchanger fibers within the oxygenator and may result in fiber rupture and failure. Although the Quadrox-D uses a new type of fiber (polymethylpentene), the fibers still accumulate charge, and over time, that charge could exceed the dielectric strength and fail. However, many solutions exist to lower, if not completely eliminate, this static build-up.

The ideal solution to eliminate unwanted static charge is to make sure the water lines are attached to the Quadrox oxygenator with an integrated heat exchanger; this effectively dissipated any built up charge, as tested in the control group, which is suggested by the manufacturer. The method by which this dissipates the built up static charge may be through the properties of the heat exchanger material—polyurethane. Polyurethane is a polymer that is used in electronic components to protect against mechanical shock by enclosing those components. This can dissipate the electric charge that is otherwise built up if the water lines are not attached.

Another method used to reduce pump-induced static charge that can be used is adding a shunting capacitor (12). The shunt would be completed by encasing the tubing between the patient and the pump with aluminum foil and connecting it to the base of the pump stand by means of a clip, thereby grounding the circuit and eliminating the potential for a spontaneous discharge (3). This method may be acceptable for dissipating any built up charge before discharging spontaneously, causing a potential fiber leak; however, this may create an unintentional secondary risk of a trip hazard for operating room personnel or, if a heavy clip is used, may cause too much strain on the lines between the table and pump.

Third, an alternative method might include using an internal protection system or an external protection system. Both methods use the concept of short circuits. A short circuit allows a charge to flow along a different path than the one intended. This in turn dissipates the static build-up as it is created. The internal protection system uses a gold wire in the oxygenator to inhibit any static build-up. The external protection system uses a connection between the arterial temperature port and a port in the H/C circuit (5). The external protection system is still used today and can be easily created by bioengineering. An additional option may include using a biohead console, which does not produce any static build-up (5).

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