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Electrostatic Potential Generated During Extracorporeal Pump Prime Circulation Before Cardiopulmonary Bypass Initiation

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Abstract: The development of electrostatic potentials generated during cardiopulmonary bypass (CPB) procedures using polyvinylchloride (PVC) tubing in conjunction with roller pumps has been previously documented. The resulting damage from the electrostatic discharge (ESD) has been reported to affect gas transfer devices, but details of potential damage to electronic components commonly used during extracorporeal circulation have not been similarly described. The purpose of this study was to measure the ability of a triboelectric potential to be generated from a primed, circulating, adult CPB pump before the initiation of CPB. Two identical adult CPB circuits were assembled: one incorporating a roller pump and the second incorporating a centrifugal pump mechanism. Primed pumps were circulated (1–6 LPM), and evidence of generated triboelectric potentials was evaluated using a digital multimeter (Fluke 8062 A). The ESD generated from an adult CPB circuit using a roller head configuration elicited a charge in excess of 600 DC V. An identical circuit constructed with a centrifugal pump mechanism did not produce any measurable charge. Sensitive electrical components in the CPB hardware platform may be damaged by ESD potential spikes of this magnitude. Preventative measures, such as circuit charge dissipation, may reduce the potential for such damage when using PVC tubing. **Keywords:** electrostatic potential, electrostatic discharge, cardiopulmonary bypass, polyvinylchloride tubing. *JECT. 2007;39:39–42*

The generation of an electrostatic charge is a commonly encountered phenomenon that is induced by the contact and separation of two similar or dissimilar materials. Development of a static charge in this manner is known as triboelectric charging (1). Although virtually all surfaces may be triboelectrically charged, insulating materials such as polyvinylchloride tubing (PVC), which prevent or limit the flow of electrons across its surface, are capable of generating a proportionally greater amount of electrostatic charge potential (1). Additional factors influencing the degree of generated triboelectric charge include the area of contact, the speed of separation, and relative humidity. If accumulated electrostatic charge is allowed to be transferred from one material to another, an electrostatic discharge (ESD) event occurs, often with detrimental effects to ground path sensitive electronic equipment.

The development of electrostatic potentials generated during cardiopulmonary bypass (CPB) procedures using PVC tubing in conjunction with roller pumps has been established (1–4). The resulting damage from ESD has been reported to affect gas transfer devices, but details of potential damage to electronic components commonly used during extracorporeal circulation has not been similarly documented (1–4). The purpose of this study was to measure the ability of a triboelectric potential to be generated from a primed, circulating, adult CPB pump before the initiation of bypass and to characterize the potential for electronic vulnerability to ESD damage in the pump electronic platform.

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MATERIALS AND METHODS

Two identical adult CPB circuits consisting of a Stöckert SIII pump platform (Sorin Group, Milano, Italy), Trillium

Affinity NT oxygenator (Medtronic, Minneapolis, MN), MVR 1600 venous reservoir (Medtronic), EL-402 cardiotomy reservoir (Medtronic), custom adult tubing pack incorporating a class VI medical grade ½ × 3⁄32 in. untreated, shore grade 71 PVC tubing boot (Medtronic), and BCD 4:1 cardioplegia (Sorin) were assembled. A centrifugal pump console (Medtronic Bio-Console 550) and pump head (Medtronic BP-X80) mechanism were incorporated into the second test circuit in place of the integral roller head assembly of the SIII pump. The occlusion setting of the arterial roller pump was determined by the nondynamic method (5) and was not altered thereafter. The pumping mechanisms of the additional roller heads in the Stöckert SIII platform were powered-down throughout the test procedure. Pump console grounding was provided by hospital grade electrical outlets; no additional ground path was established during experimentation. Prime consisted of 2 L Plasmalyte-A (Baxter Healthcare, Deerfield, IL), 25 g albumin, 22 mEq sodium bicarbonate, and 10,000 U porcine heparin.

Electrostatic (triboelectric) potentials were determined from the primed circuits by two means: static charge generation and continuous charge generation (Table 1). Static charge determinations were characterized by circulating test circuit prime at flows ranging from 1 to 6 L/min for 1 minute. After 1 minute, pump flow was stopped, and determination of ESD potential was assessed using a digital multimeter (model 8062A; Fluke Corp., Everett, WA) and a 100-mHz digital storage oscilloscope (model 2230; Tektronix, Beaverton, OR) placed in contact with the fluid path and an earth ground. The ESD potential was averaged for each flow from 10 trials to minimize error.

Continuous static charge generation was analyzed at test circuit flows ranging from 1 to 6 L/min without interrupting pump flow. The ESD potential was determined under these conditions in identical fashion to the static charge determination test group. Manufacturer specifications for pump platform operational characteristics were professionally assessed, and verification of compliance was documented before testing. The influence of relative humidity (RH) on charge generation was also studied. Determination of electrostatic potentials in each experimental modality, static charge generation, or continuous charge generation was conducted at high (38%) and low (18%) RH through the manipulation of operating room environmental control systems. The RH was recorded with a unit supplied digital hygrometer. The representative RH conditions were chosen to reflect normal (38%) and abnormal RH (18%) published standards for operating rooms (6). Ambient temperature was kept constant under all experimental conditions (21.8°C). A heating/cooling unit was not used during testing, and ambient temperature reflected pump prime conditions.

Table 1. Experimental data collection matrix.

	Static charge (DC) volts (1 minute)	RH 38%	RH 18%
Roller pump	1–6 L/min		
Centrifugal pump	1–6 L/min		
	Continuous charge (DC) volts	RH 38%	RH 18%
Roller pump	1–6 L/min		
Centrifugal pump	1–6 L/min		

RH, relative humidity.

RESULTS

A summary of the results of the static charge generation is shown in Figure 1. Measurement of ESD potential generated from the roller pump test circuit showed a direct positive relationship with flow rate in all cases. Electrostatic discharge potentials exceeding 600 DC V were beyond the range of measurability of the multimeter under test conditions. The influence of RH yielded an indirect relationship with generated charge. RH conditions of 18% produced higher static voltages than RH conditions of 38% at similar flows in this model.

No detectable accumulated static charge was found in the centrifugal pump model at any flow or humidity level (Figure 1). Determination of the continuous direct current voltage (DC V) generated within the roller pump circuit also revealed a direct positive relationship with flow rate. At a constant pump flow output of 6 L/min, a continuous voltage of 15.0 DC V was observed at 38% RH. RH conditions of 18% produced a continuous voltage of 26.0 DC V at the same flow.

No detectable continuous static charge was observed in

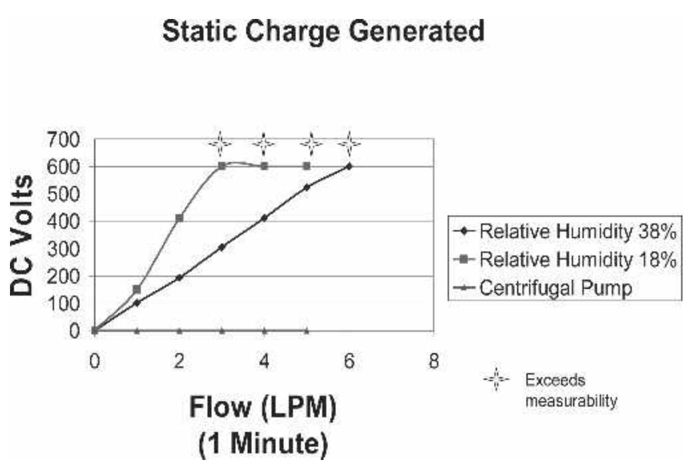

Figure 1. Static charge generation at 1-minute pump flow. RH, relative humidity; DC Volts, direct current volts; LPM, liters per minute.

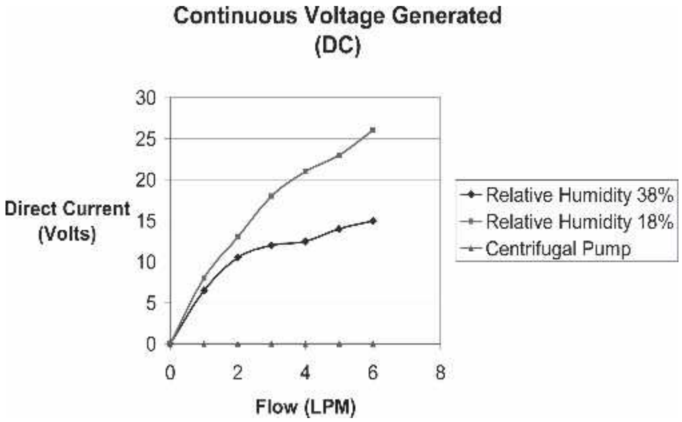

Figure 2. Continuous voltage generated. RH, relative humidity; DC Volts, direct current volts; LPM, liters per minute.

the centrifugal pump model at any flow or humidity level (Figure 2).

DISCUSSION

The results of this study provide further evidence that a substantial electrostatic (triboelectric) charge may be generated during extracorporeal pump prime circulation using a roller pump mechanism and PVC tubing. Triboelectric charging is generated from the repeated contact and separation of the PVC tubing in the raceway of roller pumps and is directly related to the rotation speed of the pump. Static charges reportedly produced in this fashion range from 600 to 2200 DC V (1,4). ESD occurs when the accumulated triboelectric charge is transferred from materials of differing electrical potentials, such as that through ground-path sensitive electronic equipment commonly found on extracorporeal pump platforms.

Damage to electronic components is determined by the ability of a device to dissipate the energy of the discharge or withstand the voltage levels involved (7). Test procedures continue to be developed, but it is known that ESD damage can occur within electronic circuitry at relatively low voltage levels of 10–100 V (7). As we have demonstrated, the potential exists for ESD damage to complex roller pump monitoring circuitry at virtually all flows, if the triboelectric charge is allowed to accumulate.

Additional considerations involve the human health risk of electrical voltage discharge. Applying Ohm's law ($I = V/R$), where I = amperes, V = DC volts, and R = resistance in Ohms (Ω), we can calculate the bodily effect of the charges generated within the extracorporeal circuit. If a conservative estimate (15,000 Ω) (7,8) of electrical resistance through an ungloved, dry human hand is used, we estimate the amperage to be in the range of 40–60 mA (0.04 A = 600 Vdc/15,000 Ω). Classification of the bodily effect of this charge is defined as "painful" and well beyond the threshold of perception (9).

In an effort to mitigate the detrimental and painful effects of triboelectric charge accumulation, we offer three simple solutions. The first solution is to continually circulate water through the heat exchange mechanism of the oxygenator any time the pump prime is circulating. This procedure will effectively provide a ground path for the charge through the heater/cooler, provided the heat exchange mechanism in the oxygenator is of a conducting material such as stainless steel. A second equally effective solution is to dissipate the charge through a line that equalizes the charge between the fluid path and the pump. This line, in our system, is an insulated, wire-cable connection between the pump chassis and the venous temperature monitoring port. The venous temperature port in this method provides a pathway for charge equalization to the charged fluid compartment. The exact method of accomplishing this task in other CPB systems should be evaluated by qualified professionals, such as an in-house biomedical engineering staff or electrical engineer. This method of charge equalization has been proven very effective in other studies (2), and measurement of generated electrostatic potentials while using these suggested charge dissipation methods in our study failed to produce a detectable charge in either intervention. Finally, while not evaluated in this study, the substitution of PVC tubing for silicone rubber tubing in pump contacting surfaces has reportedly ameliorated this condition in prior experimental studies (1,2,4).

A less feasible alternative to the suggested methods of ESD dissipation is the use of a centrifugal pump mechanism. As our results show, a triboelectric charge is not generated within the rotational flow of a constrained vortex pump. This alternative, while effective, requires a commitment of additional technological and financial resources that may burden limited budgets.

As we have shown, a substantial triboelectric charge is generated in roller pumps using PVC tubing. This charge has the potential to damage sensitive electronic components in the extracorporeal pump platform and is of sufficient magnitude to cause a "painful" discharge event to humans without the use of proper protective or preventative measures. We suggest a thorough evaluation of all roller pump systems for their potential to produce an ESD event. A proactive approach to this problem may produce unanticipated benefits.

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