An Initial Evaluation of a Novel Anesthetic Scavenging Interface

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Waste anesthetic gas scavenging technology has not changed appreciably in the past 30 years. Open reservoir systems entrain high volumes of room air and dilute waste gases before emission into the atmosphere. This process requires a large vacuum pump, which is both costly to install and, although efficient, operates continuously and at near-full capacity. In an era of increasing energy costs and environmental awareness, carbon footprint reduction is a priority and a more efficient system of safely scavenging waste anesthetic gases is desirable. We tested a low-flow scavenger interface to evaluate the potential for cost and energy savings. The use of this interface in a suite of 4 operating rooms reduced scavenging flow from a constant 37 L/min to a value equal to the fresh gas flow (usually 2 L/min) for each anesthesia machine. Using the ventilator increased this flow by approximately 6 L/min because of the exhaust of ventilator drive gas into the scavenging circuit. Daytime workload of the central vacuum pump decreased from 92% to 12% (expressed as duty cycle). The new system produces energy savings and may increase vacuum pump lifespan. (Anesth Analg 2011;113: 1064–7)

Waste anesthetic gas has been scavenged from the operating room (OR) environment for >30 years. Prompted by a possible association between trace levels of nitrous oxide and teratogenesis in OR personnel, standards were recommended (although never federally implemented) in the United States to limit occupational exposure to 25 ppm nitrous oxide and 2 ppm volatile (halogenated) anesthetic.[1] To achieve these levels, it was necessary to implement either passive (direct external exhaust) or active (vacuum system) scavenging methods.[2] The primary method used throughout the United States and Europe is an active gas scavenging system (AGSS), whereby exhausted gas from the anesthesia machine is removed by an open manifold connected to a vacuum source. This scavenging interface entrains and evacuates waste gas with relief from excessive levels of both positive and negative pressure in the breathing circuit. This balance is achieved either with relief valves that open to atmosphere with a slight pressure gradient (<5 cm H_2O) or a valveless "tube-within-a-tube" system. Although many hospitals and ambulatory surgical facilities are equipped with dedicated scavenging systems (separate pump and piping), older installations may use the medical vacuum pipeline systems to exhaust waste anesthetics.[3]

Although current technology is simple and reasonably safe, it requires that large pumps run 24 hours per day, accompanied by an unavoidable energy cost. This energy expenditure might be reduced through better scavenging system design.

We sought to design and test a more efficient scavenging interface. Design requirements included the same levels of positive- and negative-pressure relief, as well as durability and fail-safe operation.

METHODS

Anesthetic scavenging interface valves were fabricated according to the schematic shown in Figure 1. A sensitive pressure sensor, electrically powered solenoid, and standard positive- and negative-pressure relief valves were installed in an airtight metal enclosure. A 3-L reservoir bag was attached to add compliance to the system. Power to the sensor was provided by a low-voltage DC supply (to eliminate any risk of spark or ignition) and all electrical components were physically isolated from the (oxygen-containing) waste gas stream. The intent of the design was to ensure that the scavenging outflow remain occluded until a positive pressure of 0.5 cm H_2O from the anesthesia machine exhaust was detected within the enclosure. The solenoid would then open until the internal pressure decreased to negative 0.5 cm H_2O, thus emptying the reservoir bag and dynamically titrating evacuation flow to immediate needs (Fig. 2). As a fail-safe, the solenoid was chosen to remain normally open, assuring that the interface would revert to a continuous-flow AGSS configuration in the event of a power failure.[4] The system was bench tested to ensure that the solenoid opened at 0.6 ± 0.3 cm H_2O and that the positive-pressure relief valve did not open at inlet flows <50 L/min. United States Food and Drug Administration review under the 510(k) regulation was obtained, and local IRB review determined that the proposed testing did not qualify as human research.

A suite of 4 ORs was equipped with the new dynamic gas scavenging system (DGSS) interfaces, and measurements of total scavenging system flow and anesthetic concentrations (downstream from the interface) were obtained before and after the installation. The ORs were

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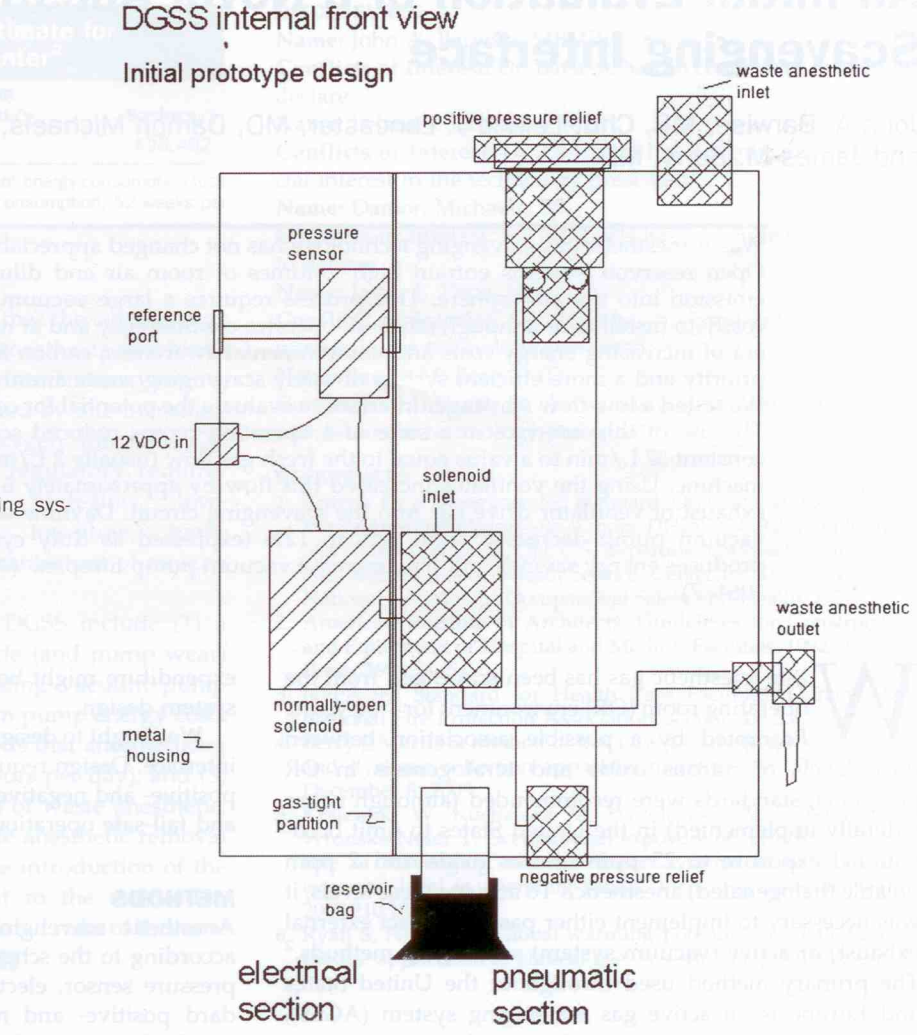

Figure 1. Prototype dynamic gas scavenging system (DGSS) design.

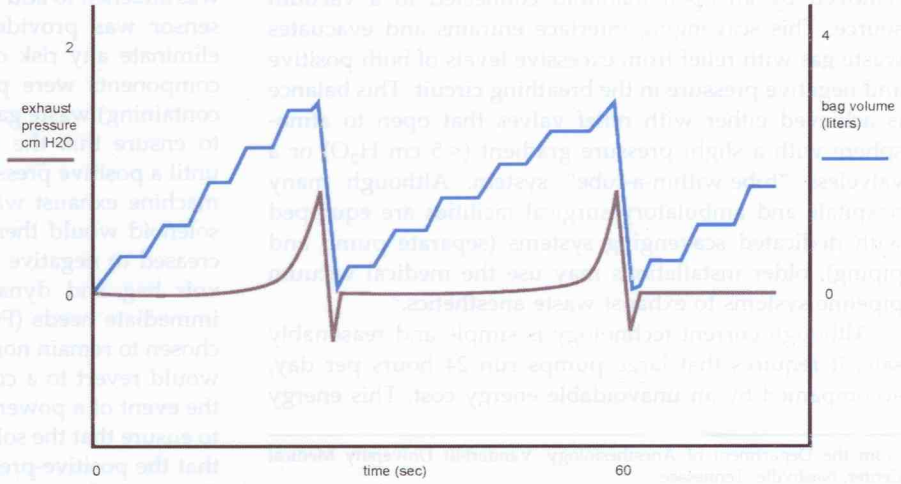

Figure 2. Depiction of typical pressures and volumes during dynamic gas scavenging system use.

equipped with Aestiva (GE Healthcare, Madison, WI) anesthesia machines; the active gas scavenging reservoirs were removed and the waste anesthetic output of each machine (including the anesthetic gas monitor exhaust line) was connected directly to the input of the new interface (Fig. 3). The hospital waste anesthetic line was connected to the new interface after verification that evacuation flows and pressures were within hospital standards (15–20 in. Hg vacuum and 10 cubic ft./min minimum flow).

In the initial evaluation, the machines were studied with a standard 3-L reservoir bag (Vital Signs, Totowa, NJ) serving as a test lung. Sevoflurane was delivered from a

Figure 3. Dynamic gas scavenging system in use.

vaporizer set at a constant 2% dial concentration. Fresh gas flows of 2 L/min and 5 L/min were used both with and without controlled ventilation (minute ventilation of 5.2 L). Scavenger gas flows were measured (5-minute samples, in duplicate) at the scavenger interface outlet with a sensitive flowmeter (RespiCal T300; Allied Healthcare Products, St. Louis, MO), and anesthetic concentrations were measured with an infrared analyzer (Philips M1026B; Philips Medical Systems, Andover, MA).

Subsequently, the systems were placed in regular clinical use for 6 months, and data were gathered on failure rates and trace gas exposure. Trace anesthetic concentrations were measured with a Miran SapphIRe infrared monitor (Thermo Scientific, Waltham, MA). The central vacuum pump for the suite of 4 ORs was monitored before and after the DGSS installation for duty cycle at 10 AM (active ORs) and 10 PM (no cases). Duty cycle was defined as (time pump running)/(total time monitored) over 3 operational cycles (approximately 10 minutes).

RESULTS

Waste gas flows from each anesthetizing location, using the preexisting AGSS, averaged 37 ± 0.5 L/min. After installation of the DGSS, flows (with ventilator off) were 2.0 ± 0.1 L/min (equal to the fresh gas flow from the machine). Using a sevoflurane vaporizer dial setting of 2%, concentrations in the waste gas flow were 0.1% before and 1.9% after installation. Using the ventilator (tidal volume 650 mL, rate 8/min), waste gas flow was 8.0 ± 0.2 L/min and the concentration was 0.55%. With 5 L/min fresh gas flow, concentrations in the waste gas flow were 0.3% before and 1.9% after installation. Using the ventilator (same settings), waste gas flow was 10.8 ± 0.2 L/min and the concentration was 0.90% (Table 1).

During routine use, no failures were noted during the 6-month trial period. Random environmental monitoring for volatile anesthetics revealed 2 episodes of anesthetic release (10 and 25 ppm). These resulted from a leak in the DGSS positive-pressure relief in one instance and a poorly sealed reservoir in the other.

Using fresh gas flows of 2 L/min with 6 L/min ventilator drive gas flow through the waste anesthetic system, the central vacuum pump duty cycle decreased after installation of the DGSS from 92% to 12% when the ORs were active and from 92% to 1% during inactive periods.

DISCUSSION

We were able to demonstrate significantly reduced waste anesthetic scavenging flows with the DGSS. The use of the system reduces vacuum pump duty cycle and decreases energy cost.

Originating with longstanding occupational standard recommendations, waste anesthetic scavenging systems are now the de facto standard.[5] AGSS interfaces require a constant flow of 35 to 75 L/min from each OR during normal operation, or approximately 353,000 to 756,000 L/wk. This is largely entrained room air, because anesthetic exhaust does not occur continuously. If, as some surgery centers do, the scavenging system is disconnected at the end of each work day, average use would be reduced to 84,000 to 180,000 L/wk. The DGSS reduces the required flows per OR to 2 to 8 L/min, or 4800 to 19,200 L/wk, reducing scavenging flows by 94% and eliminating the need for manual (dis)connection of scavenging systems each day.

Assuming commercial energy pricing of $0.15 per kilowatt hour and 400 W of pump use allocated to each OR, the cost per OR is $9.24/wk for 168 hours of vacuum pump use. The cost savings at our institution was calculated from the change in scavenging vacuum duty cycle from 92% to 8%, reducing cost per OR per week from $9.24 to $0.81. At a device cost of $1000 each, return of investment would occur in approximately 24 months, based on energy costs alone (Table 2). Our suite of 4 ORs is served by a single (dual-pump) system, and annual replacement of both pumps is required at a cost of $3000. We were unable to generalize the cost savings attributable to increases in life expectancy of other vacuum pumps, because hospital installations vary widely.

Table 1. Flow and Concentration of Waste Anesthetic from a Single GE Aestiva Before and After New Scavenger Interface (Dynamic Gas Scavenging System [DGSS]) Installation

Fresh gas flow (L/min)	Ventilator	Aestiva OEM scavenger flow (L/min) (mean ± SEM)	Sevoflurane concentration (%)	Post-DGSS installation flow (L/min) (mean ± SEM)	Sevoflurane concentration (%)
2	On	37 ± 0.5	0.1	8.0 ± 0.2	0.55
2	Off	37 ± 0.5	0.1	2.0 ± 0.1	1.90
5	On	37 ± 0.5	0.3	10.8 ± 0.2	0.90
5	Off	37 ± 0.5	0.3	5.0 ± 0.2	1.90

Table 2. Energy Cost Savings Estimate for Vanderbilt University Medical Center[a]

Current system energy cost/y	Converted system (DGSS) energy cost/y	Savings/y
$31,230	$2738	$28,492

[a] Calculation based on 65 operating rooms, current energy consumption less dynamic gas scavenging system (DGSS) energy consumption, 52 weeks per year.

One shortcoming of the system is that the cost savings are reduced when it is used with anesthesia machines that dispose of ventilator drive gas into the scavenging system. This practice was implemented by one manufacturer to reduce the venting of oxygen into the OR environment, although there is no regulatory requirement. The conversion from a high-flow, low-concentration waste stream to low-flow, high-concentration also increases the concentration of oxygen in the waste anesthetic system.

The potential advantages to the DGSS include (1) a reduction in vacuum pump duty cycle (and pump wear) and/or the ability to downsize existing vacuum pump installations; (2) a reduction in vacuum pump energy costs by limiting pump activity to the periods that anesthetizing locations are active (rather than 24 hours per day); and (3) the creation of a concentrated stream of waste anesthetic, facilitating new technology for volatile anesthetic removal from the waste stream.[6] However, the introduction of the DGSS does add another component to the evacuation system; some failure modes and associated risks of this new system may remain to be identified.

DISCLOSURES

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Conflicts of Interest: Dr. Barwise has no conflicts of interest to declare.
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