

A REEMERGENCE DEVICE FOR THE POSTANESTHESIA CARE UNIT

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Abstract—Hypercapnia is frequently used to accelerate emergence from anesthesia in the OR, but not in the post anesthesia care unit (PACU). To this end, a reemergence device has been proposed that will take advantage of hypercapnia to reduce recovery time and number of adverse clinical events experienced in the PACU. Interestingly enough, little has been reported concerning the respiration parameters (i.e. CO_2 , O_2 , and anesthetic levels as well as tidal volume and minute volume) experienced by patients in the PACU. In order to determine the design criteria for such a device, we need to collect data regarding a patient's status in the PACU. It is our hope to design a device similar to the QED-100 (Anecare, Salt Lake City, UT), that is small, mobile, versatile, and easy to operate so that it can be used in a wide variety of situations. This paper discusses the steps and system being designed to collect this data as a foundation for this work.

INTRODUCTION

THE cardiovascular and respiratory systems work in tandem to provide the necessary gas exchange for cellular metabolic activity throughout the body. The respiratory system exchanges O_2 and CO_2 between the atmosphere and blood; the circulatory system delivers the O_2 to cells throughout the body and transports CO_2 —a byproduct of cellular respiration—from the cells back to the lungs. When CO_2 levels fluctuate, the cardiovascular and respiration systems are adjusted to compensate. For example, if the arterial partial pressure of CO_2 ($PaCO_2$) rises, respiration will increase and vasodilation will occur, increasing blood flow and gas exchange in order to flush the body of excess CO_2 . When $PaCO_2$ is reduced, the opposite occurs. In the OR, this principle is frequently taken advantage of to aid patients during recovery from anesthesia.

Anesthetic vapors can be removed in the same way that excess CO_2 is flushed from the body. In this way, induced hypercapnia or elevated $PaCO_2$ can be used to accelerate a patient's recovery from anesthesia[1], [2]. A device developed in our lab called the QED-100 (Anecare, Salt Lake City, UT) is a device that accomplishes this task during the emergence phase of anesthesia in the OR (Figure 1)[3]. This device incorporates a rebreathing reservoir to induce hypercapnia and a charcoal filter to soak up expelled anesthetic



Fig. 1. The QED-100 device used to induce hypercapnia in patients immediately following surgery. A rebreathing hose elevates CO_2 levels while a charcoal filter soaks up expelled anesthetic gas. (www.anecare.com)

gases. Studies have shown that the QED-100 is capable of reducing emergence times by approximately 55%; however this device is only used in the OR until the patient is conscious and able to maintain a patent airway and then they are transported to the PACU to continue recovery until hospital discharge criteria are met[3], [4], [5].

The incidence of adverse clinical events is much higher in the PACU than the OR. Studies have shown that of 42,000 patients monitored, 23–24% experienced complications in the PACU, while only 3.8–5.1% encountered difficulties in the operating room[6], [7], [8]. As a patient becomes more alert in the PACU, a greater awareness of pain is attained, resulting in the administration of additional analgesics, which can react synergistically with trace amounts of anesthetic and induce any number of adverse clinical events, including difficulties breathing and even loss of consciousness.

To help remedy this situation, a device has been proposed for use in the PACU that will take advantage of hypercapnia in order to reduce recovery time and the number and severity of adverse clinical events. The goal is to integrate the functionality of the QED-100 with a standard oxygen mask with which patients and hospital

staff are already familiar; however, the design criteria for such a device is quite different from those used for the QED-100. In contrast to the OR where ventilation is performed and monitored closely by an anesthesia machine, a patient in the PACU is conscious and breathing on their own—albeit an irregular, shallow, and slow breathing pattern due to sub-anesthetic levels of drug still present in their body. In this state they are at greater risk of hypoxia, and often supplemental oxygen is given to compensate. The use of a hypercapnia-inducing device, like the QED-100, in this setting would further increase the risk of hypoxia. Therefore, the design criteria must include a way to maintain adequate oxygenation while still inducing hypercapnia.

Two methods have been considered to accomplish this task: a modified oxygen mask that incorporates the function of the QED-100, including a rebreathing hose and charcoal filter with a port for supplemental oxygen; or a standard oxygen mask supplied with a mixture of O_2 and CO_2 . Both have their advantages and disadvantages. The rebreathing mask makes use of the available CO_2 that the patient produces, but the simple addition of an oxygen port to the mask may dilute the rebreathed air sufficiently as to diminish or even cancel the hypercapnic effect of rebreathing. Also, the rebreathing hose and charcoal filter add bulk to the mask, which may make it cumbersome. The standard mask with a mixture of O_2 and CO_2 requires nothing extra in way of the mask, but does require additional equipment to supply the mixture of gases. In either case, determining the optimal gas mixture to induce hypercapnia for a patient with an irregular breathing pattern is difficult because CO_2 , minute volume, and even anesthetic levels are typically not monitored in the PACU, like they are in the OR, and very little information has been published regarding these parameters in the PACU. Hence, the first step towards designing a hypercapnia-inducing device for the PACU is to understand the relevant respiratory parameters encountered in the PACU. This paper addresses the work currently being done to obtain this information.

MONITORS

We will collect information from patients recovering from anesthesia in the PACU. Two monitors will be used: the Capnomac Ultima (Datex, Helsinki, Finland) and Resptrace Calibrator (Ambulatory Monitoring, Inc., Ardsley, NY). The Capnomac Ultima is capable of measuring CO_2 , O_2 , and anesthetic levels as well as tidal volume, and minute volume. To obtain accurate volume measurements, the patient must wear a tight fitting mask, and unfortunately many patients are irritated by even the loose fitting oxygen mask presently used in the PACU.

Also, supplemental oxygen will most likely be given to the patient during this process, which will interfere with the volume measurements. The Resptrace monitor is an alternative approach to measuring volume.

The Resptrace monitor provides a method of measuring tidal volume and minute volume without using a mask. It measures the expansion of the chest and abdomen due to breathing using impedance readings from special bands placed around the patient, which should be tolerable since they are laying down and moving very little. The impedance reading can then be calibrated to produce volumetric information.

With this configuration the tidal volume and minute volume will be measured using the Resptrace and the CO_2 , O_2 , and anesthetic levels will be measured using the Capnomac Ultima through a nasal cannula, which patients generally tolerate better than the mask.

Another advantage of using the Resptrace for volumetric measurements is that the patient can be tested with other breathing devices, like a mask with a mixture of CO_2 and O_2 gases, as mentioned, or a rebreathing device like the QED-100, without interfering with the flow measurement.

Custom software is being developed to integrate the two monitors into one system that will sample and record relevant information from both monitors simultaneously. Both monitors have analog outputs that can be sampled using the USB-1208LS analog-to-digital converter (Measurement Computing, Middleboro, MA). To calibrate the Resptrace, the patient must breath into a sealed mask for 30 s so that flow data can be recorded using the Capnomac Ultima. Once the Resptrace is calibrated the mask will be replaced with a nasal cannula and monitoring will begin.

SOFTWARE

Figure 2(a) shows a screenshot of the software with the raw waveforms from the Capnomac Ultima and Resptrace displayed. This screen allows the user to validate that the system is collecting data and working properly. The green waveform is from the Resptrace, which is a sum of the impedance readings from the chest and abdomen bands. The red is CO_2 , the white is O_2 , the pink is anesthetic, the yellow is volume, and the blue is flow. The pulses seen at the peak of the volume waveform are flags that the Capnomac Ultima generates to signal the beginning of a new breath.

Figure 2(b) shows a screenshot of the calibration screen: the red waveform is from the Capnomac Ultima, the green is from the Resptrace. In order to view and record the tidal volume and minute volume using



Fig. 2. Screenshot of the software written to integrate the Capnomac Ultima and Resptrace into one system to monitor patients recovering in the PACU. (a) Raw waveforms of Capnomac Ultima and Resptrace. (b) Calibration screen where green is the Resptrace and red is the Capnomac.

the Resptrace data, an algorithm is currently being developed to analyze the calibrated volumetric waveform in real-time to determine the tidal volume and minute volume.

The next step in development will be to test and verify the workflow of this system so that data can be collected easily and consistently in the PACU.

CONCLUSIONS

The data collected in the PACU regarding a patient's respiratory parameters will be of great interest since little has been published concerning this aspect of recovery from anesthesia, especially in light of the higher risk of adverse clinical events that can occur in the PACU. Using this data as a foundation, we can gain a better understanding of how a patient recovers in the PACU. This data will also serve to validate a numerical model and bench test model that have already been developed, showing the interaction between rebreathing and supplemental O_2 . Given the data and models, we hope to develop a device that takes advantage of hypercapnia while providing adequate oxygenation in order to accelerate and make safer the recovery from anesthesia in the PACU.

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REFERENCES

- [1] D. J. Sakata, N. A. Gopalakrishnan, J. A. Orr, J. L. White, and D. R. Westenskow, "Hypercapnic hyperventilation shortens emergence time from isoflurane anesthesia." *Anesth Analg*, vol. 104, no. 3, pp. 587–591, 2007.
- [2] —, "Rapid recovery from sevoflurane and desflurane with hypercapnia and hyperventilation." *Anesth Analg*, vol. 105, no. 1, pp. 79–82, 2007.
- [3] R. R. Blocker, D. J. Sakata, N. A. Gopalakrishnan, J. A. Orr, and D. R. Westenskow, "Clinical evaluation of the qed-100 emergence device," *Anesthesiology*, vol. 105, no. A853, 2006.
- [4] D. J. Sakata, N. Gopalakrishnan, J. A. Orr, and J. White, "Clinical evaluation of a device to speed emergence from sevoflurane anesthesia," *Anesthesiology*, vol. 103, p. A796, 2005.
- [5] D. Sakata, J. Orr, and D. Westenskow, "Evaluation of a device to speed emergence from inhaled anesthetic," *Anesthesiology*, vol. 99, p. A576, 2003.
- [6] R. Hines, P. G. Barash, G. Watrous, and T. O'Connor, "Complications occurring in the postanesthesia care unit: a survey." *Anesth Analg*, vol. 74, no. 4, pp. 503–509, 1992.
- [7] D. K. Rose, M. M. Cohen, D. F. Wigglesworth, and D. P. DeBoer, "Critical respiratory events in the postanesthesia care unit. patient, surgical, and anesthetic factors." *Anesthesiology*, vol. 81, no. 2, pp. 410–418, 1994.
- [8] C. Mamie, W. Habre, C. Delhumeau, C. B. Argiroffo, and A. Morabia, "Incidence and risk factors of perioperative respiratory adverse events in children undergoing elective surgery." *Paediatr Anaesth*, vol. 14, no. 3, pp. 218–224, 2004.