University of Queensland Vital Signs Dataset: Development of an Accessible Repository of Anesthesia Patient Monitoring Data for Research

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BACKGROUND: Data recorded from the devices used to monitor a patient's vital signs are often used in the development of displays, alarms, and information systems, but high-resolution, multiple-parameter datasets of anesthesia monitoring data from patients during anesthesia are often difficult to obtain. Existing databases have typically been collected from patients in intensive care units. However, the physical state of intensive care patients is dissimilar to those undergoing surgery, more frequent and marked changes to cardiovascular and respiratory variables are seen in operating room patients, and additional and highly relevant information to anesthesia (e.g., end-tidal agent monitoring, etc.) is omitted from these intensive care databases. We collected a set of high-quality, high-resolution, multiple-parameter monitoring data suitable for anesthesia monitoring research.

METHODS: Vital signs data were recorded from patients undergoing anesthesia at the Royal Adelaide Hospital. Software was developed to capture, time synchronize, and interpolate vital signs data from Philips IntelliVue MP70 and MP30 patient monitors and Datex-Ohmeda Aestiva/5 anesthesia machines into 10 millisecond resolution samples. The recorded data were saved in a variety of accessible file formats.

RESULTS: Monitoring data were recorded from 32 cases (25 general anesthetics, 3 spinal anesthetics, 4 sedations) ranging in duration from 13 minutes to 5 hours (median 105 min). Most cases included data from the electrocardiograph, pulse oximeter, capnograph, noninvasive arterial blood pressure monitor, airway flow, and pressure monitor and, in a few cases, the Y-piece spirometer, electroencephalogram monitor, and arterial blood pressure monitor. Recorded data were processed and saved into 4 file formats: (1) comma-separated values text files with full numerical and waveform data, (2) numerical parameters recorded in comma-separated values files at 1-second intervals, (3) graphical plots of all waveform data in a range of resolutions as Portable Network Graphics image files, and (4) graphical overview plots of numerical data for entire cases as Portable Network Graphics and Scalable Vector Graphics files. The complete dataset is freely available online via doi:102.100.100/6914 and has been listed in the Australian National Data Service Collections Registry.

DISCUSSION: The present dataset provides clinical anesthesia monitoring data from entire surgical cases where patients underwent anesthesia, includes a wide range of vital signs variables that are commonly monitored during surgery, and is published in accessible, user-friendly file formats. The text and image file formats let researchers without engineering or computer science backgrounds easily access the data using standard spreadsheet and image browsing software. In future work, monitoring data should be collected from a wider range and larger number of cases, and software tools are needed to support searching and navigating the database. (Anesth Analg 2012;114:584–9)

Patient vital signs data are often used in research, for example designing novel monitoring displays,[1–4] improving alarm algorithms,[5–7] and developing decision support algorithms.[8] Researchers typically have access to vital signs data from 2 types of sources. Clinical monitoring data from patients in intensive care units are available from specialized databases such as PhysioBank,[9] MIMIC II,[10] and IMPROVE,[11] but data from patients undergoing anesthesia in the operating room are either seldom available or the datasets are limited to a subset of monitored variables, such as CapnoBase for respiratory monitoring.[12] Clinical data can be collected on an ad hoc basis for research purposes,[13,14] but this can be challenging due to the proprietary communications protocols used by medical equipment, the need to time-synchronize data from multiple sources, and the higher demands on data quality for scientific research compared to clinical monitoring.[15] Alternatively, patient simulators, such as the Advanced Simulation Corporation Body Simulation (Point

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Roberts, WA) or METI Human Patient Simulator[16] (Sarasota, FL), provide realistic representations of vital signs data during steady-states, but they are less realistic during transitional phases[17] or with patients experiencing pathological conditions. Furthermore, simulators often do not simulate artifacts such as noise, sensor disconnections, and interference.[18,19] Our aim was to create a repository of vital signs data suitable for research.

METHODS

Design

This study received ethical approval from the Royal Adelaide Hospital and The University of Queensland, and the requirement for written informed consent was waived. The study goals were to (1) create a database of vital signs data recorded from patients undergoing anesthesia; (2) include at least 30 cases where monitoring data were recorded for the entire case (from sensor placement at induction until sensor disconnection after emergence); (3) collect data from a range of cases with varying combinations of anesthetics, airways, and surgical procedures; and (4) store the data in a format that can be readily accessed by all researchers without the need for specialist knowledge or software.

Apparatus

Monitoring data were recorded in 4 operating rooms at the Royal Adelaide Hospital using a combination of Philips IntelliVue MP70 monitors (Philips Healthcare, Andover, MA), Philips IntelliVue MP30 monitors, and Datex-Ohmeda Aestiva/5 anesthesia machines (GE Healthcare, Madison, WI). Monitor modules attached to the MP70 included the Multi-Measurement Server, Anesthetic Gases Module, Spirometry Module, and Bispectral Index. Only the Multi-Measurement Server was used on the MP30.

An Apple MacBook (Cupertino, CA) laptop computer was placed on a trolley, connected to the patient monitors via an Apple AirPort Extreme Ethernet hub, and connected to Port 2 of the Aestiva/5 anesthesia machines using a 15-pin RS-232 serial cable.[20] The laptop and hub were connected to an electrical outlet in the operating room using an isolation transformer.

Data Collection Software

Custom Java software running on a laptop computer communicated with the patient monitors using their Ethernet interfaces[21] and with the anesthesia machines using an RS-232 serial interface[22] to collect numerical, waveform, and alarm data. The software integrated the 3 sources of monitoring data by compensating for differences in clock skews, data sampling resolutions, and buffering intervals. A single stream of raw monitoring data were recorded in comma-separated values (CSV) text file format with a sampling resolution of 10 milliseconds using a cubic interpolation of the raw monitoring data from the patient monitors and anesthesia machines. Similar software was used in a separate study of head-mounted displays.[23]

The MP70 monitor was not able to export the CO_2 waveform data from the Anesthetic Gases Module via its Ethernet interface, therefore the MP30 was needed for capnography monitoring. A T-piece was used near the sampling port of the mask and/or airway filter to enable capnography on both monitors. In cases where only moderate sedation was provided, the MP70 monitors were not used but an MP30 monitor was used to measure CO_2 (with nasal prongs) and other variables.

The Aestiva/5 anesthesia machine was capable of exporting only 2 of its 3 airway monitoring waveforms (flow, volume, and pressure). Only the flow and pressure waveforms were recorded because volume waveforms were regenerated after data collection.

Procedure

Before the start of each case, a researcher (D.L.) set up the data collection apparatus and initiated the data recording software. Once the case had concluded and the patients were moved to the postanesthesia care unit, the researcher terminated the data recording software and removed the apparatus from the room.

Data Preparation

The raw monitoring data were processed in several steps using custom MATLAB (The Mathworks Inc, Natick, MA) scripts. First, the data files were cropped to the start (placement of the first sensor on the patient during induction) and end (removal of the last sensor from the patient after emergence) of each case. Next, the missing airway volume waveform was regenerated from the flow waveform using numerical integration (Volume = Flow$\times$ Duration). Rounding errors in the clock skew correction software sometimes resulted in 10 or 20 milliseconds of data not being recorded and was corrected by interpolating adjacent data samples. Finally, the processed data were saved in a variety of output formats.

RESULTS

Monitoring data were recorded from 32 cases ranging in duration from 13 minutes to 5 hours (median 105 min) over a period of 4 weeks. The 32 cases consisted of 25 general anesthetics (20 with an endotracheal tube, 5 with an laryngeal mask airway), 3 spinal anesthetics, and 4 sedation cases. Electrocardiography, pulse oximetry and noninvasive arterial blood pressure monitoring were used in all cases, while other monitors were used at the anesthesiologists' discretion. Table 1 lists the number of cases and the monitors used to collect the data.

There were two issues that occurred during data collection that resulted in minor artifacts. First, the MP30 monitor's sample line became occluded from excess moisture during longer cases and resulted in the temporary loss of monitoring data until manual purging by the experimenter (D.L., S.J.). Second, temporary losses of monitoring data of approximately 40 to 400 milliseconds duration in each instance occurred due to a software configuration error (Fig. 4), and appeared to affect approximately 1% of the waveform data. Specifically, the technical problem was due to the "low-pause garbage collector" option being inadvertently omitted from the Java Virtual Machine environment configuration parameters.

The primary goal of the output data formats was to ensure that researchers could easily access all of the data without needing either expert knowledge of computer-based data processing techniques, or the use of specialized

Table 1. Summary of the Types of Numerical and Waveform Vital Signs Variables Available in the Dataset, and the Number of Cases for Which Each Variable Has Data Available

Sensor	Numerics	Number of cases	Waveforms
ECG	Heart rate	32	ECG
	ST index	28	
Pulse oximetry	SpO2, pulse rate, perfusion index	32	Pleth
Capnography	etCO2, awRR	32	CO2
	inCO2	29	
Non-invasive blood pressure	Systolic, mean, diastolic	32	
	Pulse	16	
	Time remaining	28	
ABP	Systolic, mean, diastolic	4	ABP
Gas analysis	et/in: O2, N2O, MAC	29	
	etSEV, inSEV	23	
	etISO, inISO	4	
	etDES, inDES	1	
Temperature	Temp	3	
Bispectral index	BIS, SQI, EMG	5	EEG
Spirometry	Exp/insp tidal volume	3	Airway pressure, flow, volume
	Exp/insp minute volume, compliance, resistance, maximum inspired pressure	2	
Ventilator	Tidal volume, minute volume, respiratory rate	25	Airway pressure, flow, volume
	Settings: VT, MV, RR, I:E ratio, min/max P_{AW}	28	
	Settings: PEEP	11	
	Ventilator switched on/off	24	

ECG = electrocardiogram; SpO2 = blood oxygen saturation %; Pleth = plethysmograph; etCO2 = end tidal CO2 concentration; awRR = airway respiratory rate; inCO2 = inspired CO2 concentration; CO2 = carbon dioxide concentration; ABP = arterial blood pressure; et = end-tidal concentration; in = inspired concentration; O2 = oxygen; N2O = nitrous oxide; MAC = minimum alveolar concentration; SEV = sevoflurane; ISO = isoflurane; DES = desflurane; BIS = bispectral index; SQI = signal quality index; EMG = electromyography; EEG = electroencephalography; exp = expired; insp = inspired; VT = tidal volume; MV = minute volume; RR = respiratory rate; I:E ratio = inspired:expired ratio; min Paw = minimum airway pressure; max Paw = maximum airway pressure; PEEP = positive end-expiratory pressure.

software tools. Data from each case were therefore archived in 4 different file formats for convenience:

1. Full Data: all waveform and numerical parameters plus alarms recorded as CSV files where each row in a file represents a 10-millisecond data sample (Fig. 1), and each case was split into separate files where each file was limited to 10 minutes of monitoring data to maintain compatibility with the row limits of Microsoft Excel (Microsoft Corporation, Redmond, WA)[a,b];
2. Trend Data: numerical parameters and alarms also recorded as CSV text files with each row representing a 1 s sample;
3. Waveform Plots: graphical plots of waveform data (such as electrocardiogram and CO_2) saved as portable network graphics (PNG) images in 10 s, 30 s, 1 min, 5 min, and 10 min time resolutions (Fig. 2); and
4. Case Plots: graphical overview plots of numerical data (such as heart rate) for an entire case saved as PNG and scalable vector graphics (Fig. 3).

The complete dataset, including all numerical, waveform, and alarms data, is freely available online via doi:102.100.100/6914[c] and is listed in the Australian National Data Service Collections Registry (discoverable via Research Data Australia).[d]

DISCUSSION

The dataset presented in this article differs from prior repositories of clinical monitoring data in 3 main ways. First, the present dataset includes entire cases of patients undergoing anesthesia for surgery (where the patients experience rapid and dramatic vital sign changes during the induction and emergence phases of anesthesia and during surgery), in contrast to prior repositories that primarily consist of intensive care unit monitoring data. Second, the present dataset recorded a wide range of numerical variables, waveforms, and alarms, instead of a limited set of core variables or those of particular interest to specific research projects. Finally, all of the monitoring data in the present study were made available in accessible text and image file formats that can be manipulated using standard desktop office software.

The accessible CSV text file and PNG image formats provides researchers without engineering or computer science backgrounds (such as clinicians, human factors, or medical informatics experts) with easy access to vital signs data for a range of situations that frequently occur during normal anesthesia. The numerical data can be readily opened and visually inspected using standard spreadsheet software (Fig. 1), and the graphical waveform plots can be rapidly browsed with standard image browsing software (Fig. 2).

The present dataset has been applied during the prototyping of 2 novel anesthesia displays.[24,25] For example, during the clinical implementation of a respiratory sonification (auditory) display,[26] it was discovered that fresh gas flow losses via the mask was being inappropriately sonified, therefore sonification of fresh gas flow losses needed to be suppressed during oxygen administration at induction. Using the dataset's respiratory monitoring data, an algorithm was devised and successfully implemented without the need to conduct a separate clinical study to gather the required data.[24]

Limitations

The dataset presented here has several limitations. First, the number and range of cases in the dataset is relatively small. Second, the cases consisted of routine surgical procedures where no major critical events had occurred, therefore the applicability of the data to abnormal event detection are

[a] Text files that are larger than 65,536 rows cannot be imported to Excel 97, Excel 2000, Excel 2002 and Excel 2003. Available at: http://support.microsoft.com/kb/120596. Accessed April 11, 2011.
[b] Excel specifications and limits (Microsoft Office Excel 2007). Available at: http://office.microsoft.com/en-us/excel-help/excel-specifications-and-limits-HP010073849.aspx. Accessed April 11, 2011.

[c] The database is accessible online at http://dx.doi.org/102.100.100/6914.
[d] http://services.ands.org.au/home/orca/rda/view.php?key=102.100.100%2F6918.

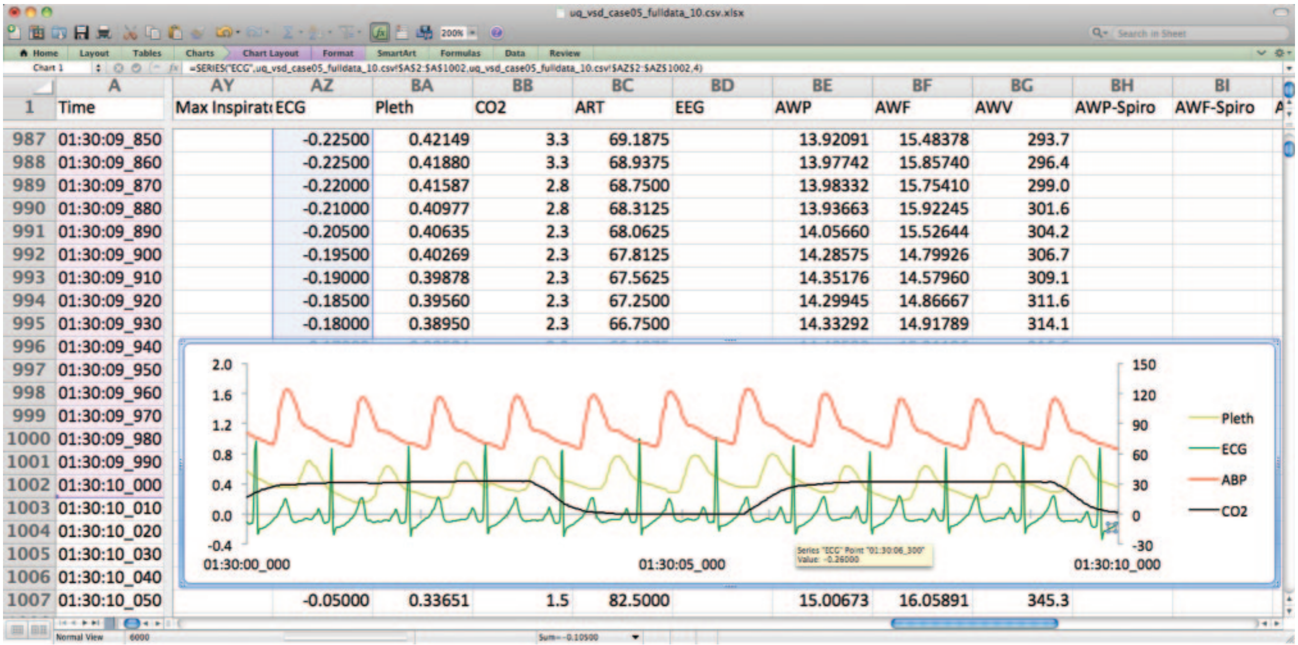

Figure 1. Screen capture illustrating how standard spreadsheet software (Microsoft Excel, Redmond, WA) can be used to open and examine one of the dataset's high-resolution comma-separated values files (full data). Each row of the spreadsheet represents a 10-millisecond sample of all recorded variables. The waveform data can be plotted using Excel's standard graphing command; in this case, 10 s of the electrocardiogram, photoplethysmogram (pulse oximetry), arterial blood pressure, and expired carbon dioxide concentration were plotted.

Figure 2. Screen capture showing how the Apple Mac OS X (Cupertino, CA) operating system's Preview software can be used to rapidly browse through the dataset's graphical plots of waveform data (waveform plots). There is also similar functionality in Microsoft Windows. In this example, waveforms were plotted for a 10-s segment of the case beginning at 1 h, 42 min, and 50 s after initial sensor placement. Excerpts of the waveforms for teaching or research purposes can be easily created using the copy-and-paste command.

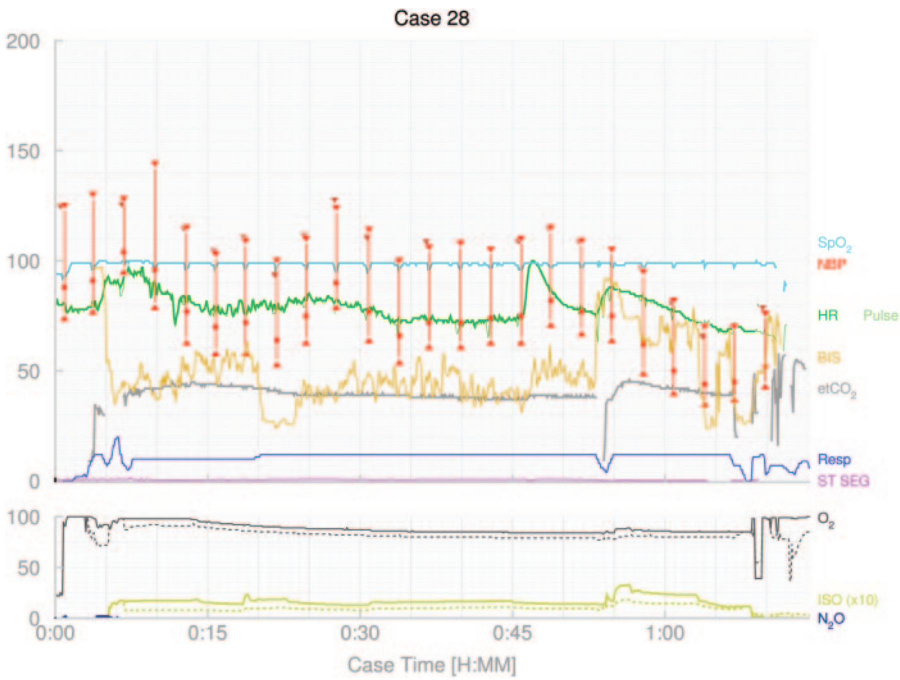

Figure 3. Numerical monitoring data (trend data) from a case in the dataset plotted across the duration of the entire surgical case (case plots).

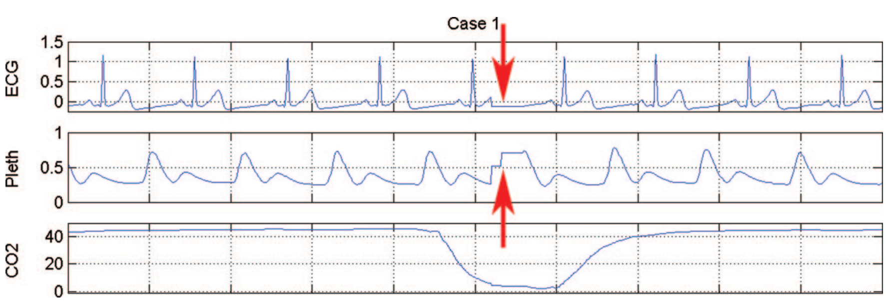

Figure 4. The red arrows highlight a type of artifact in the waveform data that could not be removed during processing. These artifacts were due to misconfiguration of the data collection software environment and resulted in short periods of data loss (flat lining) ranging from 40 to 400 ms in each instance.

limited. Third, sensor status metadata (such as signal quality indicators, alarm settings, and alarm statuses) were not accessible by the data capture software and therefore not recorded, even though it would be useful for monitoring displays research. Fourth, the external influences upon the patient (medications given, surgical events, etc.) leading to changes in the measured physiological variables during the individual procedures were not recorded. This was simply an attempt to gain a high fidelity set of rapidly changing physiological data typical of a range of operations, without attempting to correlate the changes with surgical stimuli or drugs. Finally, the accessible storage format used to store the monitoring data is inherently inefficient; therefore, the scalability of the dataset is limited. One solution may be to provide user-friendly software tools for extracting accessible file formats out of more efficient storage formats when needed.

Future Work

Future work includes collecting data from a larger variety and number of cases, developing software that can "play back" the recorded vital signs data into simulators[27,28] and clinical patient monitors,[29] developing tools for searching and navigating the database, and automating data capture by programmatically determining operating room occupancy.[30]

DISCLOSURES

Name: David Liu, PhD.
Contribution: This author helped design the study, conduct the study, analyze the data, and prepare the manuscript.
Conflicts of Interest: The Department of Anesthesiology (University of Utah) receives funding from Philips Medical Systems for research unrelated to this work described in this article. Neither the University of Utah nor Philips Medical Systems were involved with the study design or collection of data.
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