Data Article

Multivariate physiological recordings in an experimental hemorrhage model

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\section*{ABSTRACT}

In this paper we describe a data set of multivariate physiological measurements recorded from conscious sheep ($N = 8; 37.4 \pm 1.1$ kg) during hemorrhage. Hemorrhage was experimentally induced in each animal by withdrawing blood from a femoral artery at two different rates (fast: 1.25 mL/kg/min; and slow: 0.25 mL/kg/min). Data, including physiological waveforms and continuous/intermittent measurements, were transformed to digital file formats (European Data Format [EDF] for waveforms and Comma-Separated Values [CSV] for continuous and intermittent measurements) as a comprehensive data set and stored and publicly shared here (Appendix A). The data set comprises experimental information (e.g., hemorrhage rate, animal weight, event times), physiological waveforms (arterial and central venous blood pressure, electrocardiogram), time-series records of non-invasive physiological measurements (SpO$_2$, tissue oximetry), intermittent arterial and venous blood gas analyses (e.g., hemoglobin, lactate, SaO$_2$, SvO$_2$) and intermittent thermodilution car-
A detailed explanation of the hemodynamic and pulmonary changes during hemorrhage is available in a previous publication (Scully et al., 2016) [1].

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### Specifications table

| Subject area             | Physiology                                                                 |
|--------------------------|---------------------------------------------------------------------------|
| More specific sub-       | Multivariate physiological monitoring: hemodynamic, cardiovascular and      |
|  ject area                | pulmonary variables                                                        |
|                          | Critical care monitoring                                                  |
| Type of data             | Digitized times series in European Data Format (EDF) and CSV               |
| How data was acquired    | Continuous waveforms and variables were recorded using a data acquisition  |
|                          | system through invasive transducers or noninvasive electrode sensors.      |
|                          | Intermittent measurements from laboratory blood gas analyses were also    |
|                          | recorded by technicians and transformed to digital formats. All data were  |
|                          | synchronized and consolidated into a zip file with a specific time stamp  |
|                          | for each time series entry.                                               |
| Data format              | Raw synchronized and combined into EDF and CSV formats                    |
| Experimental factors     | Data were continuously recorded in consecutive phases throughout the      |
|                          | course of the experiment: baseline, hemorrhage, post-hemorrhage,          |
|                          | transfusion and post-transfusion. Interventions were applied during        |
|                          | hemorrhage and transfusion phases in which blood has been drawn or        |
|                          | re-injected back to the animal, respectively. Each animal underwent two   |
|                          | hemorrhages separated by at least 3 days at two different hemorrhage      |
|                          | rates (1.25 ml/kgBW/min or 0.25 ml/kgBW/min).                             |
| Experimental features    | Data recorded from large animals during experimental hemorrhages at two   |
|                          | different rates. A wide range of continuous and intermittent measurements |
|                          | has been acquired from each animal to reflect physiological changes and   |
|                          | variabilities with response to hemorrhage.                                |
| Data source location     | Data was originally recorded at Department of Anesthesiology, University  |
|                          | of Texas Medical Branch, Galveston, Texas, USA.                           |
| Data accessibility       | Data is shared to be publicly available for users in this article (Appendix |
|                          | A).                                                                       |

### Value of the data

- To investigate the effects of hemorrhage rate on various physiological system responses in an animal model.
- To evaluate the performance of physiological measurements estimated from waveform analysis algorithms in continuous monitoring of patient status during acute hemorrhage.
- To develop novel biomarkers and smart monitoring indices of hemorrhage using continuous measurements and machine learning algorithms compared to standard clinical measurements such as blood gas analysis.
- To develop analytical algorithms for physiological waveform feature detection or signal quality assessment under stable and unstable physiological conditions.

### 1. Data

This data set includes physiological waveforms, continuous variables and intermittent laboratory measurements of blood samples and cardiac output estimations acquired during experimental...
Table 1
Description of physiological waveform signals and continuous variables recorded in each animal.

| Type                        | Recording                  | Sensor and locations                                      | Data Acquisition System | Sampling time |
|-----------------------------|----------------------------|-----------------------------------------------------------|-------------------------|---------------|
| Physiological waveform signals | Arterial blood pressure (ABP) | Polyvinylchloride catheter implanted at right femoral artery | PowerLab (ADInstruments) | 250 samples per second<sup>a</sup> |
|                             | Pulmonary arterial pressure (PAP) | Swan-Ganz catheter implanted at common pulmonary artery | PowerLab (ADInstruments) | 250 samples per second<sup>a</sup> |
|                             | Central venous pressure (CVP) | Swan-Ganz catheter implanted at common pulmonary artery | PowerLab (ADInstruments) | 250 samples per second<sup>a</sup> |
|                             | Electrocardiogram (EKG) | Ag-AgCl electrode patches secured to lower limbs and left rear limb | PowerLab (ADInstruments) | 250 samples per second<sup>a</sup> |
| Continuous variables        | Peripheral oxygen saturation (SpO₂) | Pulse-oximeter probe secured to tail | Masimo Radical-7 | One sample per every 2 s |
|                             | Cerebral tissue oximetry (rSO₂<sub>cerebral</sub>) | NIRS optical tissue oximetry secured to forehead | Nonin SenSmart Model X-100 | One sample per every 4 s |
|                             | Thigh muscle tissue oximetry (rSO₂<sub>thigh</sub>) | NIRS optical tissue oximetry secured to thigh muscle | Nonin SenSmart Model X-100 | One sample per every 4 s |
|                             | Urinary output rate (UO rate) | Foley catheter implanted at urinary bladder | Bard Medical | One sample per every 60 s |

<sup>a</sup> The original sampling rate of 1000 Hz has been reduced to 250 Hz.

<sup>b</sup> rSO₂<sub>thigh</sub> was measured from two thigh locations on the same side in all animals.
hemorrhage in an ovine model. Physiological waveforms and continuous variables were recorded using different devices at variable sampling rates (Table 1). However, all recordings were consolidated, synchronized and stored to the final digital format in which a unique time vector was assigned to each variable.

2. Experimental design, materials and methods

Data was acquired from adult female sheep (N = 8; 37.4 ± 1.1 kg) under a protocol approved by the Institutional Animal Care and Use Committee at the University of Texas Medical Branch. After a 15-day quarantine period for medical examinations and adaptation to the environment, each animal was surgically prepared in a sterile operating room. To implant recording catheters and transducers, anesthesia was initiated by injecting 5 mg/kg ketamine (KetaVed; Vedco Inc., St. Joseph, MO) and maintained during the surgery with a mixture of 2–5% isoflurane (Piramal Healthcare Andhra Pradesh, India) in oxygen.

Arterial and venous lines were implanted in left and right femoral vessels to continuously record arterial blood pressure (ABP) and blood sampling; a 7F Swan-Ganz thermodilution catheter (131F7; Edwards Life Science, Irvine, CA) was placed into the common pulmonary artery to record pulmonary arterial pressure (PAP) and central venous pressure (CVP) as well as intermittent cardiac output. To avoid blood clotting, implanted lines and catheters were connected to a transducer (Truwave PX4 × 4; Edwards Life Science, Irvine, CA) and continuously flushed with heparinized saline (~3 mL/h per line). Following surgery completion, sheep were monitored for core body temperature, complete blood cell count, and any signs for discomfort, and pain. Buprenorphine (Buprenorphine SR; ZooPharm, Laramie, WY) was administrated before and after surgery for analgesia. During recovery, maintenance lactated Ringer’s solution was used (2 mL/kgBW/h) for resuscitation. There was a 7 day recovery period following surgery.

Following the recovery period, experimental hemorrhages were randomly induced to each sheep at fast (1.25 mL/kgBW/min) or slow (0.25 mL/kgBW/min) rates using a large gauge sterile tubing rotary pump (MasterFlex Model 7518-10; Cole-Parmer, Vernon Hills, IL). The experiment was started following sensor placement (non-invasive electrode patches were secured for EKG, pulse oximeter and tissue oxygenation) and instrumentation setup. Data was recorded during baseline (60 min), hemorrhage (experiment dependent), post-hemorrhage (30 min), blood transfusion (experiment dependent) and post-transfusion (30 min) periods, Fig. 1. MAP was continuously monitored during the hemorrhage and the hemorrhage was terminated when a 30 mmHg drop in MAP was observed compared to baseline MAP. During transfusion, blood was reintroduced until the animal’s MAP was restored to baseline. Following the post-transfusion period (after data recording ended) on the first
day of experiment the remaining blood was reinfused. Three (or more) days later, the experiment was repeated on each animal at the alternate hemorrhage rate of the first day [1].

Continuous physiological waveforms including ABP, PAP, CVP and EKG were recorded (sampling rate: 1000 Hz) using Powerlab data acquisition system and LabChart 7 Pro (ADInstruments Inc., Colorado Springs, CO) on a PC. Waveforms were converted to EDF format using LabChart 7 Pro and then downsampled to 250 Hz using a 4th order anti-aliasing filter, Fig. 2 (EDFbrowser 1.6; http://www.teuniz.net/edfbrowser). Continuous variables including SpO2, regional tissue oximetry and urinary output were recorded using Masimo Radical-7 pulse oximeter (Masimo, Irvine, CA), Nonin SenSmart Model X-100 (Nonin Medical, Inc., Plymouth, MN) and Foley catheter (Bard Medical, Covington, GA), respectively at different sampling rates (Table 1). At the end of experiment, recorded variables were downloaded from each device to a computer and converted to CSV.

Intermittent measurements including arterial and venous blood draws and thermodilution cardiac output measurements were made at fixed time points during the baseline, post-hemorrhage, and

| Type                | Sample                  | Measurements                                    | Device                     | Sampling time |
|---------------------|-------------------------|-------------------------------------------------|----------------------------|---------------|
| Blood-gas analysis  | Arterial samples        | Blood gas, Electrolytes, Metabolites and CO-oximetry | Blood gas system (Siemens RAPID-Point 500) | Variablea     |
|                     | Mixed venous samples    | Blood gas, Electrolytes, Metabolites and CO-oximetry | Blood gas system (Siemens RAPID-Point 500) | Variablea     |
| Cardiac output      | Thermodilution measurement | Two or three measurements were made at each time point and averaged for a single cardiac output value | Swan-Ganz thermodilution catheter | Variablea     |

a 60 min, 30 min, and 5 min before the start of hemorrhage, every 5 min (fast hemorrhage) or 20 min (slow hemorrhage) during the hemorrhage, 15 min and 30 min after the end of hemorrhage, and 15 min and 30 min after re-transfusion of blood.
post-transfusion periods (noted by the vertical lines in Fig. 1). During the fast hemorrhage, measurements were made every 5 min and during slow hemorrhage measurements were made every 20 min. (Table 2 and Fig. 1). To estimate cardiac output, a 10-mL iced saline bolus was first injected into the right artery; two or three thermodilution measurements of cardiac output were recorded using the pulmonary artery catheter. The average value for recorded cardiac outputs was saved. Arterial and venous blood samples were taken from femoral artery and mixed venous blood, respectively, in 1 cc heparinized tuberculin syringe and analyzed using a Siemens RAPIDPoint 500 (Siemens, Malvem, PA) for measurement of blood gas, electrolytes, metabolites and CO-oximetry variables including but not limited to hematocrit, total hemoglobin, oxygen saturation (SO2), partial pressure of oxygen (PO2), partial pressure of carbon dioxide (PCO2), bicarbonate (HCO3), base excess, pH, and lactate. 12 h prior to the experiment, water and maintenance fluids were removed but food was provided. During the experiment animals were able to sit and stand in the cage and were closely monitored for any symptoms or signs of discomfort. Animals were euthanized using deep anesthesia following the second experimental day [1].

Table 3
Format and content for stored files.

| Type                  | File name | Format | variables                                                                 | comments                                                                 |
|-----------------------|-----------|--------|---------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Experiment information| Info      | CSV    | Animal ID, Animal weight, Hemorrhage rate, Event times                    | General information about the experiment including but not limited to timing, animals, experimental treatments, etc. |
| Waveforms             | Animal ID._waveforms | EDF    | Header, ABP, PAP, CVP, and EKG time series                               | Header file includes animal ID, sampling rate, start date and time, and information about each waveform (labels, units, physical ranges, etc.) |
| Continuous variables  | Animal ID_SpO2 | CSV    | Time, SpO2                                                               | Continuous (low-resolution) SpO2 sampled at 0.5 Hz by Masimo pulse oximeter. |
|                       | Animal ID_rSO2 | CSV    | Time, rSO2_cerebral, rSO2_thigh1, rSO2_thigh2                           | Continuous (low-resolution) regional oxygenations sampled at 0.25 Hz by Sensmart. |
|                       | Animal ID_UO  | CSV    | Time, Urinary Output rate                                                | Continuous estimation of urinary output rate.                             |
|                       | Animal ID_Arterial blood | CSV    | Events, Time, pH, PCO2, pO2, HCO3, BE, Hct, tHb, sO2, FO2, FCOHb, FmetHb, FFHB, Na, K, Ca, Cl, Glu, Lac | Blood-gas analysis results and timings from arterial samples.             |
| Intermittent          | Animal ID_Venous blood | CSV    | Events, Time, pH, PCO2, pO2, HCO3, BE, Hct, tHb, sO2, FO2, FCOHb, FmetHb, FFHB, Na, K, Ca, Cl, Glu, Lac | Blood-gas analysis results and timings from venous samples.             |
| measurements          | Animal ID_CO | CSV    | Event, Time, Thermodilution estimated cardiac output                      | Estimated CO (average of repeated 3 measurements)                        |

a Animal ID format: “Sheep#_S” in which # refers to the assigned number to each animal (e.g. 40, 229, etc.) and $ refers to the experiment day (1 or 2).

b pH, potential of hydrogen; PCO2, Partial Pressure of Carbon Dioxide; pO2, Partial Pressure of Oxygen; HCO3, Bicarbonate; BE, base excess; Hct, hematocrit; tHb, total hemoglobin; sO2, Oxygen saturation; FO2, fraction of oxyhemoglobin; FCOHb, fraction of carboxyhemoglobin; FmetHb, fraction of methemoglobin; FFHB, fraction of deoxyhemoglobin; Na, sodium; K, potassium; Ca, calcium; Cl, chloride; Glu, glucose; Lac, lactate.
Simultaneously recorded data during different phases of the experiment were then digitized, re-arranged and stored as binary EDF or CSV file. Details for each specific recording are shown in Table 3. Not all signals were successfully recorded during all experiments. Particularly, regional oximetry measurements from thigh locations frequently dropped out during the experiments. File MissingData.csv in the zip folder includes a table noting which data is available for each experiment.

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Transparency document. Supporting information

Transparency data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.dib.2018.01.053.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.dib.2018.01.053.

Reference

[1] C.G. Scully, C. Daluwatte, N.R. Marques, M. Khan, M. Salter, J. Wolf, G.C. Kramer, Effect of hemorrhage rate on early hemodynamic responses in conscious sheep, Physiol. Rep. 4 (7) (2016) e12739.