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Towards an automated multimodal clinical decision support system at the post anesthesia care unit

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ABSTRACT

Background: The aim of this study was to develop a predictive algorithm detecting early signs of deterioration (ESODs) in the post anesthesia care unit (PACU), thus being able to intervene earlier in the future to avoid serious adverse events. The algorithm must utilize continuously collected cardiopulmonary vital signs and may serve as an alternative to current practice, in which an alarm is activated by single parameters.

Methods: The study was a single center, prospective cohort study including 178 patients admitted to the PACU after major surgical procedures. Peripheral blood oxygenation, arterial blood pressure, perfusion index, heart rate and respiratory rate were monitored continuously. Potential ESODs were automatically detected and scored by two independent experts with regards to the severity of the observation. Based on features extracted from the obtained measurements, a random forest classifier was trained, classifying each event being either an ESOD or not an ESOD. The algorithm was evaluated and compared to the automated single modality alarm system at the PACU.

Results: The algorithm detected ESODs with an accuracy of 92.2% (99% CI: 89.6%–94.8%), sensitivity of 90.6% (99% CI: 85.7%–95.5%), specificity of 93.0% (99% CI: 89.9%–96.2%) and area under the receiver operating characteristic curve of 96.9% (99% CI: 95.3%–98.5%). The number of false alarms decreased by 85% (99% CI: 77%–93%) and the number of missed ESODs decreased by 73% (99% CI: 61%–85%) as compared to the currently used alarm system in the hospital. The algorithm was able to detect an ESOD in average 26.4 (99% CI: 1.1–51.7) minutes before the current single parameter system used in the PACU.

Conclusion: In conclusion, the proposed biomedical classification algorithm, when compared to the currently used single parameter alarm system of the hospital, showed significantly increased performance in both detecting ESODs fast and classifying these correctly. The clinical effect of the predictive system must be evaluated in future trials.

1. Introduction

The post anesthesia care unit (PACU) is a specialized hospital unit designed for postoperative recovery including detection and treatment of adverse events before discharge to wards with lower observation frequency, but well-documented frequent and serious complication rates, especially after major surgical procedures [1]. Even though continuous patient monitoring is standardized, it may still not be ideal, as numerous false alarms occur during the day. This in turn may lead to alarm fatigue leading to an increased risk of missed alarms [2]. Hence, methods of decreasing the number of false alarms, while keeping the sensitivity for detection of adverse events high, are needed. Furthermore, systems currently used in the hospital alarms once a predefined limit of abnormal physiological values is crossed, where a predictive system may allow for earlier detection and interventions with subsequent avoidance of adverse events and sequelae.

In the field of patient monitoring, much effort has been put into collection of multiple biomedical signals, features extracted from these, training of classification algorithms and using these to predict whether a patient is at risk for deterioration. These improved observations and classification techniques have outperformed the conventional early warning systems in multiple studies and in different hospital settings

Abbreviations: CI, Confidence interval; EMR, Electronic medical record; ESOD, Early signs of deterioration; PACU, Post anesthesia care unit

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[3–6]. Much of the recent research in this area has been aimed at the patient in the intensive care unit (ICU) [7], in the emergency department [8] or in the general ward with the latter mainly retrospectively through the use of the electronical medical record [3,9,10]. Especially for the latter, multiple modalities, both invasively as well as non-invasively recorded, have been available. Other systems use a limited number of modalities non-invasively monitored to make predictions regarding emerging deterioration in the hospitalized patient. One such system is the FDA cleared and CE marked OBS Medical Visensia Safety Index, which utilizes continuous monitoring of peripheral blood oxygenation (SpO_2), respiratory rate, temperature, heart rate, arterial blood pressure and a neural network in order to make such predictions [4].

Research similar to the above mentioned examples has not been carried out in the PACU, possibly due to the fact that patient monitoring already is standardized and continuous. However, with the high number of false alarms, it is not necessarily simple to distinguish which alarms that are important. In order to detect early signs of deterioration (ESODs) among patients in the PACU, the currently used systems, which are specified in the coming section, can sound an audible alarm, if one or more continuously monitored parameters fall outside a given range. In the ICU, where similar continuous monitoring methods are used and alarms are based on a single parameter falling outside a given range, false alarm rates of 80%–99% have been reported [2]. This fact, and since it multiple times has been shown that a better representation of the current health state of a patient is given by the combination of observations made [3–5], it is proposed that a machine learning algorithm can outperform currently used practice by combining observations made on multiple biomedical signals and provide a better outcome for the patient, while keeping the number of false alarms low. Such a system may enable prediction of ESODs to allow preventive measures.

2. Materials and methods

2.1. Study setting

Data for this study was collected between December 23rd, 2016 and January 5th, 2017 in the PACU at Rigshospitalet, University of Copenhagen, Denmark. The local ethics committee waived ethical approval due to the observational study character, and the local Data Protection Agency accepted data collection if patient consent was obtained, which was the case for all included patients before discharge from PACU (RH-2016-304). Inclusion criteria were, age ≥18 years, ability to give informed consent and admission to the PACU. The patient population consisted of unselected mixed surgical procedures (major orthopedic, abdominal, urological, vascular and gynecological) as the aim was to test the ability to detect adverse events regardless of the underlying disease or procedure. Peripheral blood oxygenation (photopletysmography), arterial blood pressure, perfusion index, heart rate and respiratory rate were collected using the IntelliVue MP5 (Philips Medical Systems, Boeblingen, Germany) and BMEYE Nexfin (Edwards Lifesciences Corporation (BMEYE), Irvine, United States of America) in 1-minute intervals. Arterial pressure was for 36% of the patients collected invasively and continuously during any period of admission. Otherwise, arterial pressure was collected non-invasively in 15-minute intervals, either as a supplement to the non-invasive arterial pressure measurements and for some patients only towards the end of admission as an alternative. In order to have similar conditions for all patients, it was chosen to collect invasively measured arterial pressure in 15-minute intervals for all patients, when no non-invasive measurements were made. Despite the fact that most data was collected continuously with a higher sampling frequency higher than 1/60 Hz, it was transferred to the recently deployed electronic medical record (EMR) in 1-minute intervals to which it is not possible to increase the rate of data transfer. For the entire patient cohort, all data was anonymized instantly and therefore no information regarding demographics was available.

Table 1
Micro events of interest with corresponding EWS score, when applicable.

Biomedical signal	Micro event	EWS score
Peripheral blood saturation	1. 94–95%	1
	2. 92–93%	2
	3. 88–91%	3
	4. 80–87%	3
	5. < 80%	3
Respiratory rate	1. 9-11 min^{-1}	1
	2. < 9 min^{-1}	3
	3. 21-24 min^{-1}	2
	4. > 24 min^{-1}	3
Heart rate	1. 41-50 min^{-1}	1
	2. < 41 min^{-1}	2
	3. 91-110 min^{-1}	1
	4. 111-130 min^{-1}	2
	5. > 130 min^{-1}	3
Systolic blood pressure	1. 101–110 mmHg	1
	2. 91–100 mmHg	2
	3. < 91 mmHg	3
	4. > 219 mmHg	3
Mean arterial pressure	1. 60–65 mmHg	N/A
	2. < 60 mmHg	N/A

As this is the first study of its kind, no formal power calculation was performed and selection of population size was instead based upon a practical approach of investigating this technique in a large population with detailed data collection. After data collection, it was deemed that the sample size was reasonable due to the high number of detected micro events and ESOD labels, and from power calculations performed after data scoring, it was found that no more data collection was necessary. However, in order to reduce the risk of type I errors, we chose a 99% confidence interval (CI) in the data analysis.

2.2. Automatic detection of micro events

As up to 24 h of continuous data is obtained from a single patient after admission to the PACU at our institution after major surgery, it is not feasible for an expert to go through an entire recording looking for ESODs manually. Doing so potentially leads to multiple errors due to fatigue. Therefore, a framework for automatic detection of ESODs was created based on the national early warning score (NEWS) [11] and general critical limits as suggested in the literature according to Table 1. These potential ESODs are denoted micro events and required a duration of at least 2 min corresponding to at least three consecutive measurements fulfilling the requirements. For the blood pressure sampled at a lower frequency, at least two consecutive measurements must fulfill the requirements. This time limit was chosen to only include clinically relevant events in the current study. If a given modality exceeded the critical limit followed by a single measurement being in the normal range and immediately exceeding the critical limit again, the event was denoted as being a single micro event and not two.

2.3. Data labeling

The automatically detected micro events were presented to two medical doctors on two different dates. One of the two is an expert in perioperative medicine and randomized clinical trials for prevention of postoperative respiratory and cardiovascular disorders, whereas the other is an expert in prediction and prevention of postoperative outcomes. The doctors were asked to label each detected micro event into either of four classes;

- Class 1: Artifact
- Class 2: Event requiring no attention