AI-driven continuous physiological monitoring to predict deterioration following surgery

Abstract

This PhD project focuses on developing AI-based predictive models for early detection of complications such as bleeding, sepsis, and myocardial injury following surgery. Using continuous postoperative monitoring in ICU and with wearable sensors, the research aims to improve on current intermittent observations by nurses. The project will utilize unique multimodal datasets from the EMUs and ICU-Heart studies, applying advanced machine learning techniques to predict clinical deterioration. The research promises to revolutionize postoperative care, reducing preventable complications and deaths. Ethical considerations, such as bias and privacy, will be carefully addressed, ensuring the models' relevance across diverse global settings.

Introduction

The failure to detect and intervene upon commonly occurring complications after surgery results in avoidable morbidity and mortality. This is termed *failure to rescue*[1]. While patient and disease factors partially explain avoidable death after surgery, health system factors such as the use of postoperative monitoring, emergent imaging, and critical care facilities are key to rescuing patients from major complications[2].

Death following surgery is due to bleeding, sepsis, or a myocardial injury in almost half of instances[3]. Prompt identification and management of these complications promises reductions in avoidable deaths. Failure to recognise deterioration in a timely manner is common. Close monitoring in the early postoperative period is important, given the median time from surgery to major bleeding (day of surgery, interquartile range 0–2), myocardial injury (day 1, IQR 0–1) and sepsis (day 6, IQR 3–11).

Continuous postoperative monitoring in ICU using the Philips IntelliSpace Critical Care and Anaesthesia system (ICCA; https://www.philips.co.uk/healthcare/product/HCNOCTN332/intellispace-critical-care-and-anaesthesia) and on wards using “wearable” sensors (https://sibelhealth.com/clinical-care/) could provide early alerts of deterioration to clinical teams allowing prompt management of serious complications[4]. Integrating raw physiological monitoring data including heart rate, respiratory rate, peripheral oxygen saturation (SpO2), pulse arrival time, skin temperature, and movement has potential. However, no validated algorithm currently exists linking these data with patient outcomes or decision cues for healthcare teams. Indeed, a recent scoping review showed studies in this area were limited by recruited patient numbers (N = 10 to 51) and methods employed[5]. There are no registered on-going largescale studies gathering multimodal waveform data and patient outcomes in the postoperative surgery period to determine the utility of this approach. This PhD will achieve this.

Research Challenge

1. Can we predict complications in surgical ICU patients?
2. Can continuous waveform data improve prediction models compared to intermittent observations by nurses?
3. Can a multimodal AI model incorporating wearable monitoring data with previous health even, healthcare imaging, current disease status, and intraoperative monitoring variables improve the discrimination of predictive models of deterioration?

About the study

This PhD will build on the work performed in the EMUs Study (Enhanced Monitoring Using Sensors after Surgery; https://clinicaltrials.gov/study/NCT06565559) and ICU-Heart (Wellcome Trust, £2.6million, PI Docherty).

The former is a collaboration with Sibel Health, with opportunities for direct collaboration within this industry partner. It uses the Sibel ANNE® One device, a wireless ICU-grade dual sensor system that provides real-time physiological monitoring. The system features two skin-mounted, bio-integrated sensors that provide continuous storage of vital sign measurements and physiological waveforms. A shadow-mode evaluation of the device is underway, with sensor and clinical data being collected contemporaneously in the clinical environment. At the time of writing (October 2024), sensor data is being collected in patients undergoing surgery in the UK, Nigeria and India.

ICU Heart integrates the continuous multi-modal monitoring for all patients within the Critical Care environment with data routinely collected as part of patients' clinical stay. Data include physiological waveforms such as ECG, invasive blood pressure, and oxygen and CO2 measurements, along with prescriptions, detailed organ support, and patient hospital records. Data is linked within DataLoch, and expansion to other Scottish sites is underway.

Data & Methodology

Sensor data is collected into onboard memory with no influence on care processes. Patients aged 18 years and older who will undergo elective or emergency major surgery procedure with a planned skin incision of 5 cm or greater will be recruited. Each contributing hospital will recruit 3-5 surgical patients per week. Patients will be consented prior to surgery, sensors attached prior to surgery, and time-stamped labelled follow-up commenced in the postoperative recovery area.

The focus of the PhD will be the exploration of the relationship of multimodal continuous waveform data with clinical events such as bleeding, sepsis, and heart attacks. The overall aim is to incorporate all available data into temporal risk prediction models. These will start with conventional machine learning models such as random forests and gradient boosted trees, and expand to integrated neural networks, such as recurrent and convolutional neural networks. The incorporation of attention mechanisms will be explored, together with different approaches to fusion of multimodal modals. Multitask models (simultaneous prediction of more than one outcome) are attractive from a clinical point of view and will also be explored.

Risk Mitigation

For EMUs, these are complex datasets combining physiological monitoring data with real-time clinical outcome detection worldwide, making them hard to assemble. Data are already being collected (one patient per day per hospital) and by the time this PhD starts we expect to have >1000 patients. ICCA data are collected in real-time in all patients in ICU in Edinburgh. This means access to unique, large, and clinically relevant datasets is guaranteed for this PhD. In the event of any problem with this, DataLoch provides access to intermittent physiological data for all patients in hospitals in NHS Lothian. This represents a back-up if necessary.

Responsible AI / Ethical considerations

This PhD will be conducted in accordance with the principles of the International Conference on Harmonisation Tripartite Guideline for Good Clinical Practice (ICH GCP). All necessary ethical approvals are already in place. Reporting will be in accordance with the TRIPOD+AI guidelines.[6]

AI prediction models raise important ethical considerations, particularly around bias, transparency, privacy, accountability, safety, and societal impact. The team running this PhD think deeply about these issues and supervise other PhDs dealing specifically with AI ethics. A particular benefit of the EMUs study is the simultaneous data collection the Global North and South. This ensures that the resulting prediction models will be as relevant to those living and working in low- and middle-income countries as to those working in environments with greater resource availability.

Expected Outcome and Impact

This PhD project will utilise unique datasets, not currently available to any other researchers in the world. The resulting models are expected to drive a paradigm shift in the management of patients following surgery, as well as to develop new AI methods aligned to the use of these multimodal data types. It is expected that resulting outputs will be published in high impact clinical journals and presented in influential AI conferences and proceedings. Importantly, the most significant impact will be improved clinical care with a reduction in the number of patients experiencing complications following surgery and those that tragically die as a result.

References

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