Continuous remote monitoring and point-of-care lung ultrasound to detect clinical deterioration and postoperative complications

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English summary

Chapter 1 provides a general introduction describing the postoperative patient population and the impact of postoperative pulmonary complications including its pathophysiology. Death after treatable complications (failure to rescue) is an important cause of mortality. An overview is given on currently used point-check patient monitoring strategies to detect clinical deterioration in an early stage. Diagnostic imaging of postoperative patients for pulmonary pathology is also described, including point-of-care lung ultrasound.

In general, the ***first part*** (**chapters 2-5**) of this thesis focuses on continuous remote monitoring. We monitored respiratory rate, peripheral oxygen saturation and heart rate in postoperative patients admitted to and intensive care unit patients discharged to the general ward. We hypothesized that early detection of aberrant vital parameters in these patients indicates clinical deterioration. Furthermore, early detection may enable the medical team to limit the impact of postoperative complications and save lives. Its current practice to use modified early warning scores on regular intervals to detect clinical deterioration of ward patients to prevent adverse events. Therefore, we proposed to use modified early warning score based on continuous remote monitoring of vital parameters to overcome this intermittent character.

The ***second part*** (**chapters 6-11**) of this thesis focuses on point-of-care lung ultrasound. We first performed a systematic review and meta- analysis of the value of chest radiograph, the current first-line diagnostic imaging modality for pulmonary symptoms in critically ill patients, and the value of lung ultrasound, the emerging and possibly the first-line diagnostic imaging modality in the near future. To expand the growing evidence, we performed multiple studies with lung ultrasound in the postoperative setting. We introduced lung ultrasound to physicians willing to adopt this imaging modality and studied point-of-care lung ultrasound to detect postoperative pulmonary complications in cardiothoracic and major abdominal surgery patients. We hypothesized that lung ultrasound could detect more (clinically-relevant) postoperative pulmonary complications than chest radiograph.

In more detail, in **chapter 2** we wrote a narrative review summarizing the current technical possibilities for continuous remote monitoring and the evidence for its application in the postoperative period. There are several medical grade continuous remote monitoring platforms available that integrate a biosensor signal with electronic patient records, allowing for automated notification of patients clinical deterioration. We conclude that continuous remote monitoring of vital signs in the surgical ward may contribute to prevent severe

complications and subsequently reduces failure-to-rescue rates, but evidence for this association is still lacking.

In **chapter 3** we studied the incidence of deviating vital signs and clinical deterioration detected by continuous remote monitoring. For this purpose, we included patients undergoing major abdominal surgery with an increased preoperative risk for the development of postoperative pulmonary complications. The respiratory rate, peripheral oxygen saturation and pulse rate were continuously remotely monitored for four postoperative days. A remote MEWS was calculated. Overall, continuous remote monitoring feasible in 97 out of 100 eligible patients (97%, 95% CI: 91 to 99%). Thirty-nine patients (40%) developed one or more postoperative pulmonary complications during the study period. We frequently found aberrant postoperative vital parameters. The remote MEWS was critical in 11.6% (0.8-20.8) of the study period in patients with postoperative pulmonary complications. Our findings suggest that continuous remote monitoring of vital signs may be useful in early detection of patients who are clinically deteriorating after major abdominal surgery.

In **chapter 4** we studied continuous remote monitoring in ICU patients discharged to the general ward. Its known that these patients are at risk for adverse events and are frequently re-admitted to the intensive care unit. We studied the incidence of aberrant vital signs measured with continuous remote monitoring and subsequently the incidence of critical MEWS. The remote MEWS was critical in 10% of the study period in these patients. Twenty-one out of 44 patients (47.7%) developed a critical remote MEWS episode. Seventeen out of 28 critical remote MEWS episodes (60.7%) were not detected by current practice of MEWS assessments. Patients with a critical remote MEWS for more than 1 hour had a prolonged hospital length of stay. We concluded that continuous remote monitoring frequently detects critical remMEWS episodes in ICU patients discharged to the general ward which were not detected with current practice MEWS assessments in more than 50%.

In **chapter 5** we studied respiratory rate monitoring during procedural sedation and analgesia in upper gastrointestinal endoscopic procedures. At present, capnography is considered the gold standard of respiratory rate monitoring but the diagnostic accuracy during these procedures is limited. Inadequate ventilation and hypoxemic events are preferentially prevented during these procedures since they could lead to serious adverse events. We evaluated photoplethysmography as a possible alternative for respiratory rate monitoring and its diagnostic accuracy in predicting hypoxemic events since respiration rate is a proxy of ventilation. We found a low level of agreement between capnography and plethysmography respiratory rate during procedural sedation in upper gastrointestinal endoscopic procedures.

Furthermore, respiratory rate derived from both capnography and photoplethysmography showed a limited ability to provide for an early warning sign in order to prevent hypoxemic events.

In the ***second part***, **chapter 6** details a narrative review about point-of-care lung ultrasound. The goal of the review was to serve as an introduction, starting point for physicians willing to adopt lung ultrasound as an imaging modality. We describe the principles of the ultrasound equipment, lung ultrasound artefacts and how to perform lung ultrasound. A decision tree is presented to differentiate between causes of acute dyspnoea. We state that point-of-care lung ultrasound is a promising diagnostic modality that can be of great assistance to the physician. It is applied directly at the bedside and can be used to follow up on disease progression and effect of therapy. It is our belief that lung ultrasound will be the most used diagnostic imaging technique in the near future and should be considered an essential extension of routine physical examination.

Chapter 8 is about, a systematic review and meta-analysis of the diagnostic value of chest radiography and lung ultrasound, when concomitantly performed, as an imaging modality for pulmonary symptoms in critically ill patients. Chest radiography is considered the first line imaging modality. However, the diagnostic accuracy is possibly limited in this setting. We aimed to evaluate the diagnostic accuracy of both imaging modalities. The imaging techniques were compared to the gold standard for evaluating respiratory pathology: computed tomography. We demonstrated that chest radiography has a low sensitivity and a reasonable specificity compared to computed tomography for detecting lung pathology in critically ill patients. When lung ultrasound was performed concomitantly, lung ultrasound proved to be vastly superior to chest radiography in terms of sensitivity with similar specificity. Lung ultrasound opts to be the first-line diagnostic tool in these patients.

In **chapter 9** we investigate the detection of postoperative pulmonary complications with lung ultrasound for following cardiothoracic surgery in a prospective observational study. Postoperative pulmonary complications are common after cardiothoracic surgery and are associated with adverse outcomes. However, little is known about the diagnostic accuracy of lung ultrasound for the detection of postoperative pulmonary complications after cardiothoracic surgery. We recruited patients undergoing cardiothoracic surgery in whom, according to standard postoperative protocol daily chest radiography was performed. Each patient underwent standardized point-of-care lung ultrasound examinations. These findings were blinded for the treating physician. Lung ultrasound detected, at an earlier point in time, more clinically relevant postoperative pulmonary complications compared to chest

radiography. Our results suggest that point-of-care lung ultrasound may be used as the primary imaging technique to screen for postoperative pulmonary complications after cardiothoracic surgery. It will probably boost bedside decision-making.

In **chapter 11,** we compared detection rates of postoperative pulmonary complications following major abdominal surgery with routine point-of-care lung ultrasound, to on demand chest radiography in a prospective observational study. Early detection of pulmonary complications in postoperative patients to prevent serious adverse events and failure to rescue piques growing interest in the literature. We describe a well defined protocol for point-of-care lung ultrasound following major abdominal surgery to detect postoperative pulmonary complications. Lung ultrasound detected more patients with postoperative pulmonary complications. The number of discordant observations with both modalities was high for atelectasis and pleural effusion, but not for pneumothorax, respiratory infection and pulmonary edema. Future research is needed to evaluate a possible role for point-of-care lung ultrasound in perioperative management of major abdominal surgery patients. Another interesting question is whether lung ultrasound can stratify the frequently detected postoperative pulmonary complications appropriately to the required treatment and thereby limit its impact.

Chapter 12 contains a general conclusion of our findings and a discussion including future perspectives. Continuous remote monitoring of vital signs frequently detects clinical deterioration in patients (defined by MEWS), that otherwise would not have been detected by standard MEWS assessments in current practice. Lung ultrasound frequently detects postoperative pulmonary complications. Future research is needed to evaluate the impact on patient outcome of all these findings.