Postanesthesia care by remote monitoring of vital signs in surgical wards

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Purpose of review
This narrative review summarizes recent insights into the role of remote monitoring of vital signs in the postoperative period in surgical wards.

Recent findings
Despite recent improvements in the safety of anesthesia and surgical procedures, postoperative complication rates are still unacceptably high. This is partly attributable to the intermittent provision of personal care to patients by nurses and ward physicians. Continuous remote monitoring of vital functions in the early postoperative period may reduce these complication rates. There are several medical-grade remote monitoring platforms available that integrate a biosensor signal with electronic patient records, enabling automated prediction or notification of patient deterioration. Most available platforms have technical limitations with respect to the accuracy of respiratory rate measurements. Of note, although the implementation of automated notifications of patient deterioration is associated with a reduced activation of acute response teams, the involvement of ward physicians in the early diagnosis and treatment of subtle changes in vital functions is increased.

Summary
Remote monitoring of vital signs in the surgical ward may contribute to prevention of severe complications and reduction in failure-to-rescue rates, although evidence for this association is still lacking. Anesthesiologists should contribute their knowledge and skills with respect to perioperative abnormalities in vital functions to improve patient safety during the postoperative period.

Keywords
biosensor, early warning score, failure-to-rescue, postoperative, telemedicine

INTRODUCTION

Despite major improvements in the safety of anesthesia and surgery, the number of postoperative complications is still unacceptably high. Postoperative complications vary among surgical procedures but rates up to 25–40% are reported [1], with readmission rates of 16–22% following high-risk procedures [2]. Postoperative complications are, therefore, a tremendous burden on hospital logistics, healthcare costs, and the quality of life of surgical patients. Anesthesiologists are highly qualified to identify relevant changes in vital functions in the early postoperative phase, and their contribution to the monitoring of surgical patients may, therefore, lead to improved outcome.

There is increased awareness that early recognition and timely management of mild or moderate abnormalities in the patient's condition, once they have occurred, may improve the quality and outcomes of postoperative care [3]. However, the organization of postoperative care is frequently inadequate to detect these mild and moderate abnormalities, leading to the development of severe complications and unplanned intensified care, also known as failure to rescue. Ghaferi *et al.* showed that failure-to-rescue rates can be particularly attributed to inconsistencies in the structure and quality of postoperative care among hospitals, as well as patient age [4▪]. Moreover, provision of personal care to patients by nurses and physicians is intermittent, and early signs of deterioration of health

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KEY POINTS

- Postoperative monitoring of vital signs in surgical patients using spot check monitors is intermittent, and early signs of patient deterioration may, therefore, be missed.
- Continuous remote monitoring of vital signs with wireless biosensors facilitates automated notification of patient deterioration and early diagnostic and therapeutic interventions.
- Implementation of automated notifications of patient deterioration is associated with reduced activation rates of rapid response teams, but increased involvement of ward physicians in the early treatment of postoperative complications.
- Anesthesiologists are highly qualified to identify relevant changes in vital functions in the early postoperative phase and should contribute their knowledge and skills to improve patient safety during the postoperative period.

may, therefore, be missed. Although hospitals try to limit staffing costs, new technological innovations such as continuous telemetric monitoring of vital parameters, also known as remote monitoring or automated notifications may be introduced to fill this gap in surgical wards.

The goal of the present review is to give an overview of the concept of remote monitoring of vital signs in the postoperative period in surgical wards, and to summarize existing evidence for the added value of this monitoring concept.

THE USE OF EARLY WARNING SCORES IN POSTOPERATIVE CARE

Preoperative risk scores constructed from patient risk profiles, the type of surgery, and intraoperative events have a moderate accuracy in the prediction of surgical risk and complications [5]. The addition of changes in postoperative dynamic clinical parameters, such as heart rate (HR), respiratory rate, blood pressure, and oxygen saturation (SpO_2) values may increase the accuracy of these risk scores. Subtle changes in these parameters, such as an increased respiratory rate or HR, may be indicative of the development of complications such as pneumonia or hypovolemia [6].

In an attempt to assess variations in vital functions, institutions implemented (modified) early warning scores [(M)EWS] to guide activation of rapid response teams (RRTs) in cases of patient deterioration [7]. This score is usually measured by nurses using spot check monitors and enables normal physiological changes to be distinguished from pathologic variation. An EWS that exceeds three points leads to intensification of monitoring, the initiation of a diagnostic work-up, and/or the start of therapeutic interventions.

Although the EWS can be used to identify and treat aberrations in vital functions in a protocolized fashion, a beneficial impact on risk reduction in postoperative failure-to-rescue rates has not yet been proven [7]. Moreover, it has been shown that a manual EWS has superior discriminative performance compared with an automated EWS using continuous data obtained from bedside monitors, mainly because of differences in the chosen thresholds for manually charted and digitally recorded respiratory rates [8,9]. However, manually charted EWS files are frequently incomplete and may be biased by the opinions of health professionals [10]. An important limitation of the EWS is a low discriminative power for early and mild abnormalities in vital functions. These scores are, therefore, mostly used for activation of response teams in cases of severe patient deterioration.

Remote technologies and automated notification systems may help to improve the appropriateness, reliability, and speed of diagnosis and therapeutic interventions in deteriorating surgical

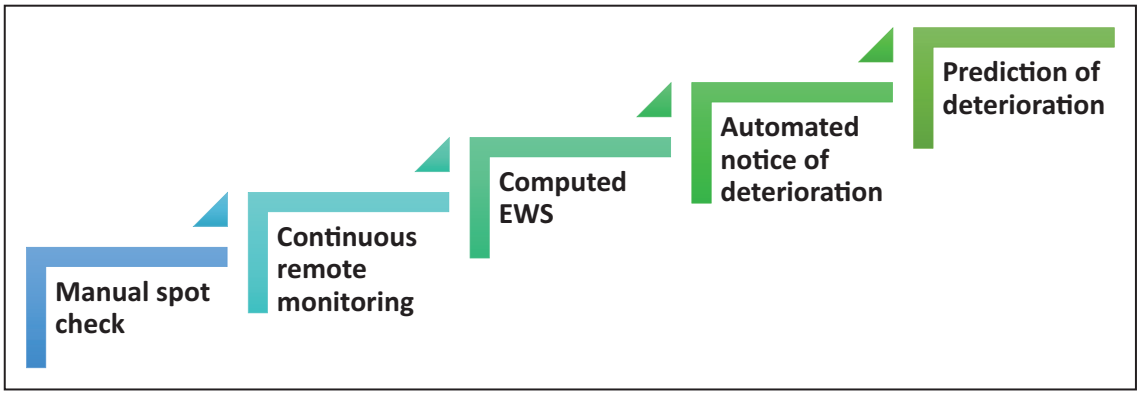

FIGURE 1. Step-up monitoring model for vital signs in hospital wards. EWS, early warning score.

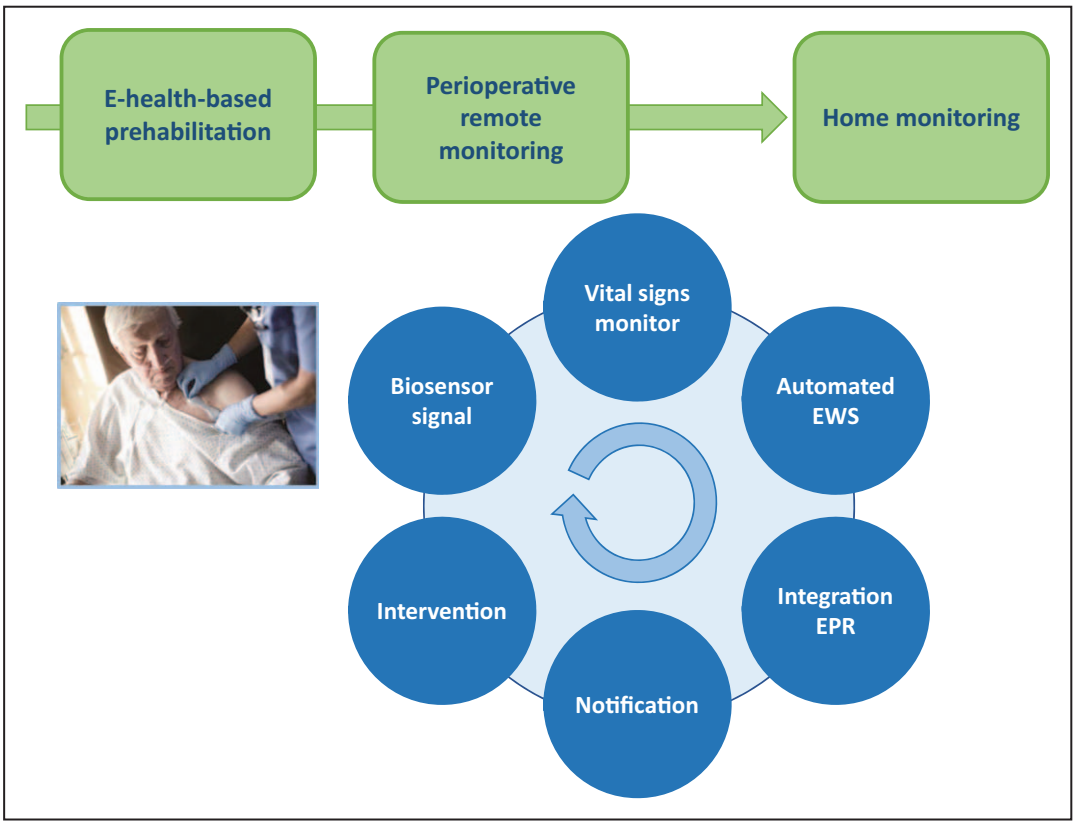

FIGURE 2. Example of the use of remote monitoring in the perioperative period. Using e-health interventions, patients are prehabilitated before surgery. During hospital admission, patients receive a biosensor that transfers information about vital signs by WiFi or radiofrequency signals to a dedicated server depicting automated EWS calculations. The vital sign monitor is linked to the hospital electronic patient record system. Abnormalities in vital signs or the early warning score are automatically notified to healthcare professionals using a computer terminal, tablet or mobile phone, supporting early interventions to improve patient health. EPR, electronic patient record; EWS, early warning score. Example of the wireless Intellivue Guardian biosensor (published with courtesy of Philips Healthcare).

patients [11,12]. The use of continuous remote monitoring of single parameters to detect mild deviations in vital signs of surgical patients is only one factor in a complex situation. Figure 1 shows a step-up monitoring model that starts with spot check monitoring of vital signs by nurses, followed by continuous wireless monitoring of vital signs in a remote fashion. More advanced steps include the automated calculation of EWS using remote monitoring signals, the automated notification of patient deterioration through tablets and smartphones, and prediction rules for patient deterioration, which are discussed below.

REMOTE MONITORING DEVICES USED IN THE SURGICAL WARD

Although there are many digital applications available that are embedded in smartphone and tablet interfaces to measure vital functions such as HR or heart activity [13▪,14], the present review reports only on remote monitoring devices using medical-grade biosensors. For medical-grade systems, the signal is transferred from a cable-less biosensor to a central receiver that is preferably connected to an electronic patient record (EPR) database. Ideally, remote monitoring systems allow free movement of the patient. Figure 2 shows an example of implementation of remote monitoring in perioperative care. Using e-Health applications, patients are monitored and prehabilitated before surgery. After hospital admission, patients indicated for postoperative hospital stay receive a biosensor that transfers vital sign recordings to a dedicated monitor and software platform. This software platform integrates the received signals with the EPR database and provides automated EWS. Healthcare professionals are notified of deviations in vital functions or EWS and prompted to initiate diagnostic or therapeutic interventions [15].

Table 1 summarizes the remote monitoring devices with WiFi or radiofrequency connectivity

Table 1. Remote monitoring devices with WiFi or radiofrequency connectivity platforms that were studied in the context of the surgical ward

Product	Remote vital signs	Automated EWS	Wireless biosensor
HealthPatch MD/VitalPatch	Single-lead ECG, HR, HR variability, respiratory rate, temperature, activity	Yes	Yes
Intellivue Guardian	HR, respiratory rate, posture	Yes	Yes
Sensium	HR, respiratory rate, temperature	Yes	Yes
ViSi Mobile System	HR, PR, respiratory rate, SpO_2, blood pressure, temperature	Yes	No
Radius-7/Patient Safetynet	HR, respiratory rate, SpO_2	Yes	No

EWS, early warning score; HR, heart rate.

platforms that were studied in the context of the surgical ward. Although there are systems that use a wireless biosensor or patch with data storage capacity (VitalPatch, Intellivue Guardian, Sensium), other systems still require some wiring between the measurement sensors and wearable remote monitor device [ViSi Mobile System (Sotera Wireless, San Diego, CA, USA), Radius-7/Patient Safetynet (Masimo International Sàrl, Neuchatel, Switzerland)]. Most systems are able to communicate with an EPR platform, pagers, tablets, and mobile phones. Patients perceive remote monitoring as a helpful tool to alleviate the nursing staff, and to reduce nightly interruptions for charting reasons, but do not believe they replace the benefits of face-to-face nursing contact [16].

TECHNICAL LIMITATIONS

Currently available remote monitoring systems still have technical limitations. A comparison between HR and respiratory rate sensors and a routine intensive care monitoring system in high-risk postoperative patients showed that for different biosensors HR was accurate, whereas the respiratory rate was outside the accuracy limit range compared with standardized monitoring [17,18] or manual respiratory rate measurements [19,20]. Photoplethysmography respiratory rate using an SpO_2 biosensor also showed a low agreement with routine capnography during procedural sedation for endoscopy [21]. The addition of end-tidal CO_2 to an automated MEWS was investigated in a patient population with a history of obesity, sleep apnea, or receiving patient-controlled analgesia or epidural narcotics undergoing elective surgery [22]. It was shown that the addition of end-tidal CO_2 alarms to an automated MEWS was feasible but resulted in a high rate of false-positive alarms. Despite the low agreement between some remotely recorded vital signs and manual or spot check measurements, the continuous trend analysis that is enabled by remote monitoring devices may have good potential as an addition to current postoperative care.

AUTOMATED CALCULATION OF EARLY WARNING SCORE DEVIATIONS AND NOTIFICATIONS

The potential benefits of automated systems for the recognition of patient deterioration was demonstrated in a study in noncardiac surgery patients, showing that nurses only detected 5% of the hypoxemic episodes that were recorded by pulse oximetry [23]. Being unaware of vital sign aberrations may cause an avoidable risk for the development of more severe complications. Two before-and-after clinical studies investigated the impact of an automated notification system for patient deterioration [24▪▪,25▪]. Patient deterioration was assessed by an EWS calculated from a combination of bedside observations and a 15 min automated evaluation of vital signs including HR, respiratory rate, SpO_2, and blood pressure. Abnormal vital signs were sent to an automated paging device. Local protocols recommended escalation of healthcare intensity or activation of an RRT when a specific EWS was exceeded. In the study by Subbe *et al.* [24▪▪], it was shown that the number of RRT notifications increased by 30%, resulting in initiation of fluid therapy, the use of bronchodilators, and antibiotics. The mortality of patients referred to the ICU was 50% lower after the implementation of automated notifications. However, the extrapolation of these results to the general surgical ward was limited, as this patient cohort included patients with a moderate-to-high risk for severe complications [24▪▪]. In a similar fashion, Heller *et al.* [25▪] implemented automated notifications in a surgical ward. In this study population, however, the number of medical emergency calls and unplanned ICU admissions was lower in the intervention cohort, whereas the number of critical notifications increased. In particular, deterioration of patient health was more frequently

treated by the physician in charge on the ward without activation of an RRT [25▪]. These findings suggest that the introduction of automated notifications of deterioration in vital signs leads to enhanced involvement of ward physicians, rather than increased activation rates of specialized response teams. Similar findings were observed in neurological and neurosurgical patients. Implementation of a vital sign monitor with automated nursing notification of alarms via smartphones was associated with a reduction in the RRT call rate, but the study was not powered to detect changes in ICU admission rates [26]. Another study showed that the implementation of an electronic dashboard with MEWS values of nonsurgical and surgical patients resulted in a higher rate of first RRT activations, whereas the overall RRT activation rate decreased [27]. An explanation for this observation was the higher awareness among ward physicians of patient deterioration after the first RRT activation. From this small number of studies, it can be concluded that the introduction of an automated EWS with notification system leads to a reduction in RRT activation in cases of severe patient deterioration and an increase in diagnostic and therapeutic interventions for subtle changes in patient condition.

MACHINE-LEARNING ALGORITHMS FOR IMPENDING PATIENT DETERIORATION

Machine learning and data mining allow the construction of models that detect deviation of normal EWS [28]. A next step in automated detection of patient deterioration is the development of patient-specific predictive algorithms using large datasets containing information of vital signs. Ghosh *et al.* [29] developed the early deterioration indicator (EDI) algorithm using spot check data of vital signs recorded in electronic patient files, and subsequently performed a validation study. The EDI scoring algorithm was based on data of stable and unstable patients and provides continuous probabilities of instability ranging from 0 to 1. EDI had a higher sensitivity and was a better discriminator of patient deterioration than a 5-point and 7-point EWS. The further development of EDI using data from wireless remote monitoring devices will further support early prediction of patient deterioration and may contribute to a reduction in the postoperative complication rate.

REMOTE MONITORING AFTER HOSPITAL DISCHARGE

The introduction of the surgical home concept and home telemedicine systems may be supportive in the reduction of postoperative length of stay. Currently, most home-based telemedicine systems for postoperative patients are limited to mobile applications that monitor the quality of recovery. In the first feasibility studies, patients used a mobile phone daily to complete a quality of recovery scale and took photographs of the surgical site [30,31]. In a second feasibility study, it was shown that a smartphone text message-based algorithm to monitor patient health following colorectal surgery was acceptable to patients and reduced the number of postoperative telephone consultations [32]. However, vital functions such as blood pressure and HR were manually measured by patients or relatives, and not by remote monitoring devices. Both studies showed that patient cooperation is an important prerequisite for the use of mobile applications that require active input. Biosensor-based monitoring devices may alternatively be used to guarantee patient compliance and to reveal early signs of patient deterioration. These systems are currently under development or have become recently available, and feasibility and efficacy studies are lacking. In specialties such as cardiology, there is extensive experience with home-based remote monitoring of patients with arrhythmias or heart failure, but with the footnote that these systems are also at risk for cybersecurity issues and hacking, warranting collaboration between stakeholders to set a standard for the level of security of these systems [33].

WHERE ANESTHESIOLOGISTS CAN FILL THE GAPS IN POSTOPERATIVE CARE

In a continuous effort to improve patient outcome, anesthesiologists should contribute to improvements in the structure and quality of postoperative care. Some suggest that this niche should particularly be filled by anesthesiologist-intensivists, who are increasingly involved in preoperative risk reduction, extracorporeal and mechanical support teams, and RRTs [34]. However, from the studies that implemented automated notification systems in surgical wards [24▪▪,25▪,27], one may conclude that remote monitoring of postoperative patients will lead to a shift from the activation of RRTs to smaller interventions in cases of mild abnormalities in vital functions. In 2015, the American Society of Anesthesiologists introduced the concept of perioperative surgical homes in order to reduce the variability in perioperative practice. The perioperative surgical home is still in its infancy and may not be fully adapted by other continents [35]. The concept of perioperative medicine, rather than anesthesiology, promotes the commitment of anesthesiologists to the outcome of surgical procedures and broader

collaboration of anesthesiologists with other healthcare providers. This also requires specific educational programs to increase the knowledge and competencies of anesthesiologists in the postoperative period [35]. Remote monitoring of vital signs may be a helpful tool in this transition of anesthesiologists to perioperative physicians.

CONCLUSION

Despite improvements in the quality and safety of anesthesia, postoperative care in moderate-to-high risk patients is still dominated by high complication rates. Intermittent monitoring of patients in the surgical ward by nurse staff and physicians is insufficient to detect mild aberrations in vital functions that could be the first sign of the development of severe complications. The introduction of continuous remote monitoring of vital functions in the postoperative period, with automated calculation of EWS and notification of healthcare providers, could lead to a shift to recognizing mild rather than severe disturbances in the patient condition [36]. This will not only result in a reduced activation rate of RRTs but can also pave a path for anesthesiologists in the field of perioperative medicine. While awaiting the evidence for a beneficial impact of remote monitoring and automated notifications on postoperative complication rates, anesthesiologists should contribute their knowledge and skills with respect to perioperative abnormalities in vital functions to increase patient safety in the postoperative period. Anesthesiology resident programs should emphasize the importance of the early postoperative period beyond the recovery ward and prepare residents for their role as perioperative physicians.

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Conflicts of interest

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- ■■ of outstanding interest

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