Remote Vision-Based Digital Patient Monitoring of Pulse and Respiratory rates in Acute Medical Wards

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Abstract

Remote Vision-Based Digital Patient Monitoring (VBPM) of pulse (PR) and respiratory rate (RR) was set up in 6 single rooms in an acute medical and an orthopaedic ward. We compared 102 PR and 154 RR VBPM measurements (from 27 patients) with paired routine nurse measurements. VBPM measurements of RR were validated by reviewing video footage. Nurse measurements of RR were often 16-18 breaths/minute, and did not match VBPM RR (overestimating at low RR and underestimating at high RR). Nurse measurements of pulse were on average 3.9 beats per minute greater than matched VBPM measurements. VBPM was unobtrusive and well accepted.

Introduction

Regular measurement of vital signs in patients on acute wards detects or predicts clinical deterioration (1). Typically, nurses measure PR with a finger oximeter, and RR by counting breaths, usually over 15 or 30 seconds. Recently Vision Based Patient Monitoring (VBPM) has made these measurements possible by remote digital technology without nurse interaction. This technique has been validated in the ICU (2) and a dialysis unit (3) and is used in mental health settings following clearance as a medical device (4). Here we evaluated VBPM in an acute medical setting.

Methods

Routine measurements by nurses (including trained clinical support members of the nursing team) were not altered in any way for this study. They followed ward protocols and the data were taken from the patients' medical records.

The VBPM software used was Oxevision (Oxehealth Ltd, Oxford, UK). This uses a wall-mounted digital camera with infra-red illuminators allowing measurement even in complete darkness. Computer analysis tracks small movements of the chest to give RR and reflectance photoplethysmography detects changes in transmitted light in the skin with each heartbeat to measure PR.

VBPM was set up in 2 single rooms on 2 adult respiratory wards at the Royal Brompton Hospital, London (RBH) and 4 single rooms on a surgical orthopaedic ward at the John Radcliffe Hospital, Oxford (JRH) with ethics committee approval (Social Care Research Ethics Committee no 17/IEC08/0026 and the East of England – Essex Research Ethics Committee no 18/EE/0221 respectively). Patients gave written informed consent. They were admitted at

RBH for treatment of acute respiratory conditions and at JRH for fractures and other acute orthopaedic conditions.

The VBPM system could be temporarily switched off by nurses but otherwise ran continuously. However, VBPM was not analysed when a nurse was in the room as it cannot reliably differentiate between two people's vital signs. Therefore, VBPM measurements were paired with nurse recordings when they were recorded within 5 minutes of each other and the paired data analysed. VBPM was not available for patient management during the course of the study and nurses were blinded to its output.

To validate the VBPM RR measurements, a reviewer was shown video clips of patients breathing. A sample of 80 short video clips drawn from 10 study patients was selected from times when the VBPM system was outputting RR measurements. The reviewer measured the breathing rate while blinded to the corresponding VBPM measurement.

We used simple descriptive statistics (distribution based) to describe the population and events and Bland-Altman analysis when comparing two different modes of measurement (I.e human vs VBM and VBM vs video analysis). As expected, given differing lengths of stay, the number of observations per patient was not normally distributed (see Figure S1).

Results

2571 hours of data were collected from 10 patients at RBH (Median (IQR) age 58 (39-72) and 17 from JRH (81, 72-90). Patient characteristics are in table S1. The data from the two hospitals was combined.

Nurse and VBPM paired measurements (n = 102) were similar for PR with nurse PR on average 3.91 (LOA: -10.5 to +18.3) bpm greater than VBPM (figures 1 and 2). There was no difference between the sites. The distribution of counts is shown in Figure S2.

Nurse measurements of RR (n= 154) were predominantly between 16 and 18 bpm, and bore no relation to the paired VBPM measurements (LOA: -8.39 to + 6.57 bpm) (figures 1 and 2). The distribution of counts is shown in S3.

Continuous recording of VBPM allowed the display of trends over time (Figures 3 and S4).

In the validation study, the independently measured anonymised video data for RR (n = 80) was within +/- 3 breaths per minute (bpm) of the VBPM measurement (root mean square error of 1.31 bpm); correlation is shown in Figure S5 with a Bland and Altman analysis shown in Figure S6.

Discussion

The results confirm that VBPM can provide continuous measurement of PR and RR in acute ward single rooms. The technology was feasible for use in these busy clinical settings as demonstrated by >2500 hours of recording. VBPM was unobtrusive and well accepted by nurses and patients.

Overall recordings of pulse rate were slightly greater than VBPM across the range of pulse rates, perhaps due to a “white coat effect” (5) that in the presence of a nurse there tends to be an increase in awareness, alertness and wakefulness of the patient leading to a faster pulse. However, VBPM PR was close to nurse recordings and the difference was not clinically significant, nor was there any systematic bias.

Measurements of RR by VBPM and nurses were substantially different. Nurse RR were usually between 16 and 18 breaths per minute, while VBPM measurements were widely spread and showed little correlation. RR measured from the visual (as opposed to digital) camera data confirmed the VBPM data, and demonstrated that the nurse data was discrepant. It is known clinically that nurses tend to report a 'normal' value for RR when they judge from observation that a patient is breathing normally, and this study confirms that tendency. Nurses underestimated RR when it was high and overestimated it when it was low (Figure 3) so that tachypnoea and bradypnea, both of which could be associated with clinical deterioration, go potentially undetected, reducing the efficiency of an early warning system if collected by a human observation.

There are other possible advantages of a VBPM system. Firstly, VBPM, by automating measurements, could allow nurse time to be reprioritised to other aspects of nursing care. For a nurse to enter a room, take observations, and subsequently record them takes at least 5 minutes per patient. For a ward of 30 patients this is 150 minutes or 2.5 hours. Secondly, patients do not enjoy being woken for observations at night and poor sleep as an inpatient is associated with excess mortality (6). VBPM reduces the need for this disturbance. Thirdly, it reduces the risk of cross infection from one patient to the next. However, an important limitation presently of VBPM is that it gives no insight into oximetry or blood pressure, both of which are useful clinical aides and a component of many clinical monitoring algorithms including the NEWS2. The eventual use of the system of course remains to be established and would need to be validated in a trial which used clinically important outcomes (e.g., unplanned ICU admission) as an outcome.

An alternative solution is low-cost single use or cleanable wearables (7-9). It is uncertain at this stage what type of technology will eventually achieve widespread clinical use, and it is further likely that the data arising from these systems may profit from automated analysis and machine learning from data sets with real life outcomes.

One use of the system may be provided by the fact that monitoring is continuous; in particular for pulse rate, while nursing observations were accurate, VBPM could, especially if subjected to automated analysis, have additional advantages not examined here, in detecting disorders of heart rhythm, such as atrial fibrillation, and of respiratory rhythm, such as sleep apnoea (Figures 3 and S4). Furthermore, VBPM could be programmed to alarm if there is no detectable pulse, respiration, or movement of the patient for 30 seconds or more for routine patients in hospital.

We conclude that VBPM is effective, convenient and has the potential to become an important mode of patient monitoring in acute clinical settings.

Figure Legends

Figure 1

Plot of pulse rate measured by a nurse (horizontal axis) and VBPM (vertical axis) (Panel A) and the same data expressed as Bland and Altman (Panel B). The data are combined from both study sites. The number of paired observations are represented by the size of each point on the graph (see legends).

Figure 2

Plot of respiratory rate measured by a nurse (horizontal axis) and VBPM (vertical axis) (Panel A), and the same data expressed as Bland and Altman (Panel B). The data are combined from both study sites. The number of paired observations are represented by the size of each point on the graph (see legends).

Figure 3

Overnight record showing continuous VBPM measurement of RR with a single nurse measurement, illustrating that the VBPM shows trends which are not clear from a single measurement. In this case VBPM respiratory rate measurements were plotted with an average line for a single patient in the room between 03:30 and 06:45 hours. The 'X' symbol represents the nurse RR measurement taken at approximately 05:00 in the morning. The vertical axis on the right-hand side displays the corresponding National Early Warning Scores.

Figure S1

The number of observations from each patient was not the same; median count per patient 4 for RR and 3 for PR. The exact distributions are shown in the histograms: Count frequency for respiratory rate (A) and count frequency for pulse rate (B).

Figure S2

Pulse rate measurements (n = 102), recorded by two methods: nurse measurements, plotted against VBPM measurements at similar times (within +/- 5 minutes of each other).

Figure S3

Respiratory rate (n = 154), recorded by two methods: nurse measurements, and VBPM measurements at similar times (within +/- 5 minutes of each other).

Figure S4

VBPM pulse rate measurements for a single patient in the room between 03:00 to 06:00 hours. The 'X' symbol represents the nurse PR measurement taken at approximately 05:35 in the morning. The y-axis on the right-hand side displays the National Early Warning Scores corresponding to the pulse rates.

Figure S5

Respiratory rates measured by a visual reviewer counting breaths from video recordings plotted against RR measured digitally by VBPM at the same time (+/- 30 seconds) in 80 measurements from 10 patients (5 from each hospital). The legend indicates the number of paired observations represented by each scatter point on the graph.

Figure S6

Bland and Altman analysis of Respiratory rates measured by a visual reviewer compared with those from simultaneous digital VBPM, as in S1.

The legends indicate the number of paired observations represented by each scatter point on the graph.

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