A pilot study of high frequency accelerometry-based sedation and agitation monitoring in critically ill patients

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The use of sedation to facilitate invasive medical care is a cornerstone of intensive care practice. Both excessive and inadequate sedation may cause harm. Excessive sedation is associated with increased intensive care unit (ICU) length of stay, duration of mechanical ventilation,[1,2] delirium[3] and mortality.[4-7] Inadequate sedation risks interference with vital supports such as endotracheal tubes or vascular access devices, increased nosocomial infections, and increased health care costs.[8-10] However, the precise monitoring of sedation is challenging.

The monitoring of sedation is currently periodic and subjective. Sedation is most commonly assessed by the Richmond Agitation and Sedation Scale (RASS). The RASS is an ordinal categorical scale from –5 to 4, with –5 signifying deep coma and +4 combativeness. A target score of –2 to 0 (asleep but easily roused) is generally recommended.[11,12] The RASS emerged as the leading sedation–agitation metric in the early 2000s because of its good face validity, inter- and intra-rater reliability, and because it shares some qualities, particularly in the motor domain, with the Glasgow Coma Scale (GCS).[11-13] However, the RASS has a number of inherent limitations. In particular, sedation can only be assessed intermittently. As a consequence, the RASS may deviate across wide ranges of sedation during the intervals between testing without clinician knowledge. Moreover, neurological changes or inadequate sedation may be detected late or missed. Finally, the RASS assesses sedation and agitation only at a single time point with no mechanism for anticipating changes in sedation or agitation.

Given these challenges, a method that allows the monitoring of sedation continuously, quantitatively, and with minimal invasiveness is desirable. Accelerometry has the potential to provide such a method because it possesses all these qualities and provides a very sensitive monitoring tool for the motor component of the patient's response to sedation. In this regard, accelerometry has been previously trialled successfully to monitor motor activity in the ICU, with increasing wakefulness associated with increasing accelerometer activity.[6] Nevertheless, to our knowledge, no ICU study has employed high resolution continuous spectral recording of wrist accelerations in relation to the RASS score.

ABSTRACT

Objective: The degree of sedation or agitation in critically ill patients is typically assessed with the Richmond Agitation and Sedation Scale (RASS). However, this approach is intermittent and subject to unrecognised variation between assessments. High frequency accelerometry may assist in achieving a quantitative and continuous assessment of sedation while heralding imminent agitation.

Design: We undertook a prospective, observational pilot study.

Setting: An adult tertiary intensive care unit in Melbourne, Australia.

Participants: 20 patients with an admission diagnosis of trauma.

Main outcome measures: Accelerometers were applied to patients' wrists and used to continuously record patient movement. Video data of patient behaviour were simultaneously collected, and observers blinded to accelerometry data were adjudicated the RASS score every 30 seconds. Exploratory analyses were undertaken.

Results: Patients were enrolled for a median duration of 9.7 hours (interquartile range [IQR], 0–22.8) and a total of 160 hours. These patients had a median RASS score of 0 (IQR, –4 to 0). A 2-minute moving window of amplitude variance was seen to reflect contemporaneous fluctuations in motor activity and was proportional to the RASS score. Furthermore, the moving window of amplitude variance was observed to spike immediately before ≥2 point increases in the RASS score.

Conclusions: We describe a novel approach to the analysis of wrist accelerometry data in critically ill patients. This technique not only appears to provide novel and continuous information about the depth of sedation or degree of agitation, it is also notable in its aptitude to anticipate impending transitions to higher RASS values.

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Materials and methods

We undertook a prospective, observational pilot study of paired wrist-mounted accelerometers in patients admitted to a tertiary ICU between January 2018 and December 2018. Adult patients admitted to the ICU, with the main reason for admission to ICU related to trauma, were eligible. Patients with movement disorders, neuromuscular blockade, or injury to the arms (precluding accelerometer placement) were excluded. Local institutional ethics approval (HREC reference: LNR/16/MH/357) was obtained, and patients or their next of kin gave consent for enrolment.

We collected data on admission diagnosis, sedative drugs administered, presence of head injury, recent psychotropic medication, age, gender, illness severity, intubation status, nursing impression regarding presence of agitation at enrolment, and prior duration of ICU stay. The GCS, Confusion Assessment Method for the ICU (CAM-ICU) and RASS scores were assessed by the enrolling clinician (MW). Our ICU employs minimally restrictive wrist restraints in patients clinically judged to be at risk for treatment interference. These restraints allow free wrist movement but limit the ability of the patient to lift the hands above the torso. Their presence or absence was also recorded.

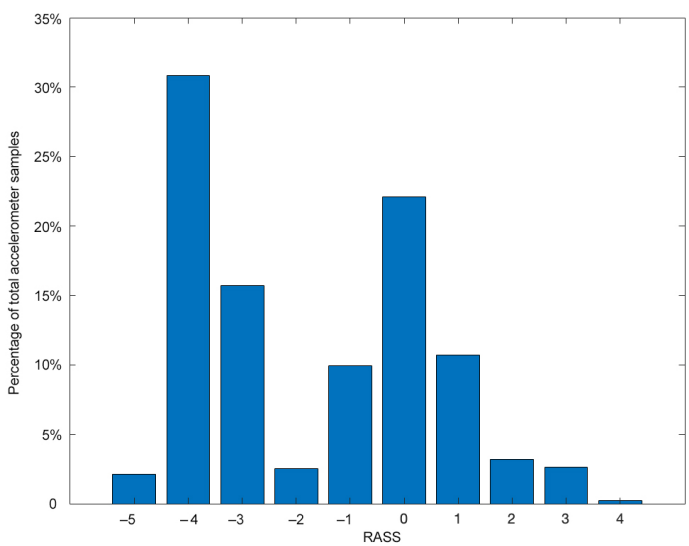
The accelerometer device used in the study was the Smart Sensor Watch G2 manufactured by Eoxys Systems (Bangalore, India) and Neuroanalytics (Melbourne, Australia). A device was applied with medical adhesive tape bilaterally over the dorsal surface of patients' distal radio-ulnar joints of both limbs (online Appendix, figure 1). These battery-powered devices transmitted data via Bluetooth (Bluetooth Special Interest Group) for about 16 hours to a nearby smartphone running a proprietary recording application.[14] Each device sensed acceleration in three axes with a sampling rate of 100 Hz using a TDK MPU-9250 accelerometer chip. Video data were simultaneously captured via a webcam connected to a laptop computer situated at the foot of the patient's bed (online Appendix, figure 2).

Recorded video data were used to retrospectively judge the RASS score every 30 seconds by two independent adjudicators (MW, LT) blinded to the accelerometry data. Agitation, if present, was observed and the RASS scored accordingly. Sedation assessment (determination of negative RASS scores) relied on observation of the nature of the patient's response to either a verbal or physical nursing stimulus. During routine clinical practice, sedation assessment is done episodically and so the RASS score was assumed to be stable at the previously determined value until nursing staff were observed to re-test the patient's level of sedation or it was apparent from audiovisual data that the patient was at a different level of sedation. Missing data occurred when the patient was being passively moved (by staff or family), when video data were unavailable (during patient exposure for personal washing and the camera was temporarily obscured), or when one accelerometer battery had drained. Missing data were excluded from analysis. The resulting data were used to compare the observed RASS score for each 30-second block with the accelerometer data.

Statistical analysis

Accelerometer data consisted of variables in four dimensions: three orthogonal acceleration vectors measured in ms^{-2} (x, y and z) recorded across time, sampled at 100 Hz. Descriptive and correlational statistics were employed to attempt to determine a relationship between accelerometer data and RASS scores. Initially a number of advanced analytical techniques were employed, including machine learning-based classification, clustering, interdirectional cross-correlation, and canonical correlation in an attempt to best describe the relationship between RASS scores and accelerometry data. These techniques were abandoned because of unnecessary computational complexity, and the requirement for a higher sample size to effectively use these techniques and achieve statistical significance. Moreover, a simpler approach examining variance of accelerometer

Figure 1. A frequency histogram of the observed Richmond Agitation and Sedation Scale (RASS) scores



power yielded consistent and proportional relationships between RASS scores and accelerometer data.

Acceleration vectors were resolved into a directionless absolute value of acceleration using a root mean square calculation.

$$\text{Magnitude of acceleration} = \sqrt[2]{x^2 + y^2 + z^2}$$

The values of the left and right wrists were averaged, yielding a single magnitude of acceleration for a given time point. These were categorised by RASS scores and accelerometry means and variances calculated for each RASS score using the MATLAB software (MathWorks, Natick, USA).

A moving window mean and variance were then derived — a moving window mean is the mean value of acceleration magnitudes recorded over a period (or "window"). To calculate this window at a given time, the acceleration values for the preceding 2 minutes were averaged. The devices recorded at 100 Hz and so a 2-minute window yielded 12 000 acceleration values; the average of these values gave the moving window mean. The moving window mean 30 seconds after this point in time would contain 75% (1.5 minutes of the same data plus the data from the intervening 30 seconds), providing a continuously updated average which reflected the previous 2 minutes from a given time point. The variance of these values is calculated from the same data in the same way.

Varying window widths allowed examination of activity at different intervals of time preceding a given time point. A window containing the preceding 2 minutes to a given time point was chosen as optimal, after trials of periods of 30 seconds up to 30 minutes. This strategy was observed to effectively capture short term changes in movements associated with arousal without being overly sensitive to a single movement. Moreover, this window width reflected the period during which patients were observed to emerge from sedation and to respond to increased (propofol) sedation when given.

Figure 2. Examples of accelerometry versus time at Richmond Agitation and Sedation Scale (RASS) scores –4, 0 and 4

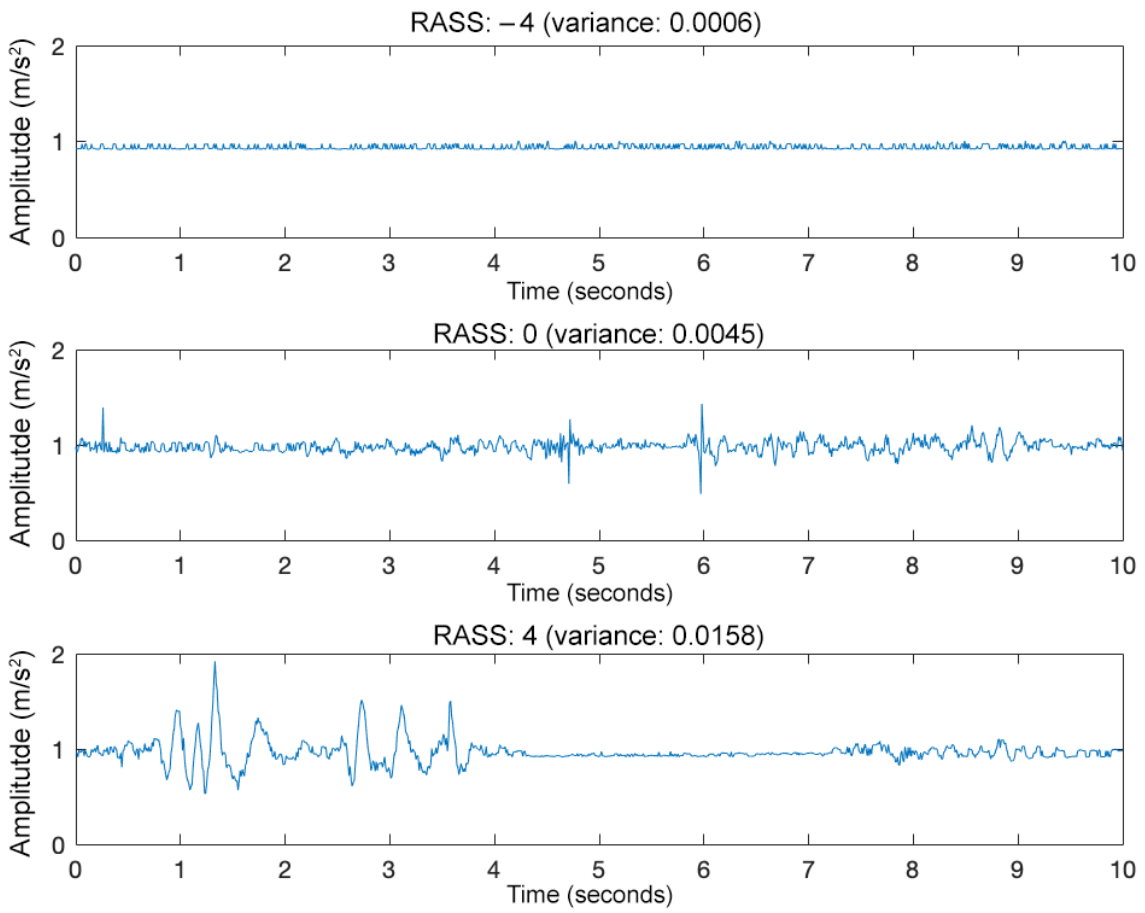
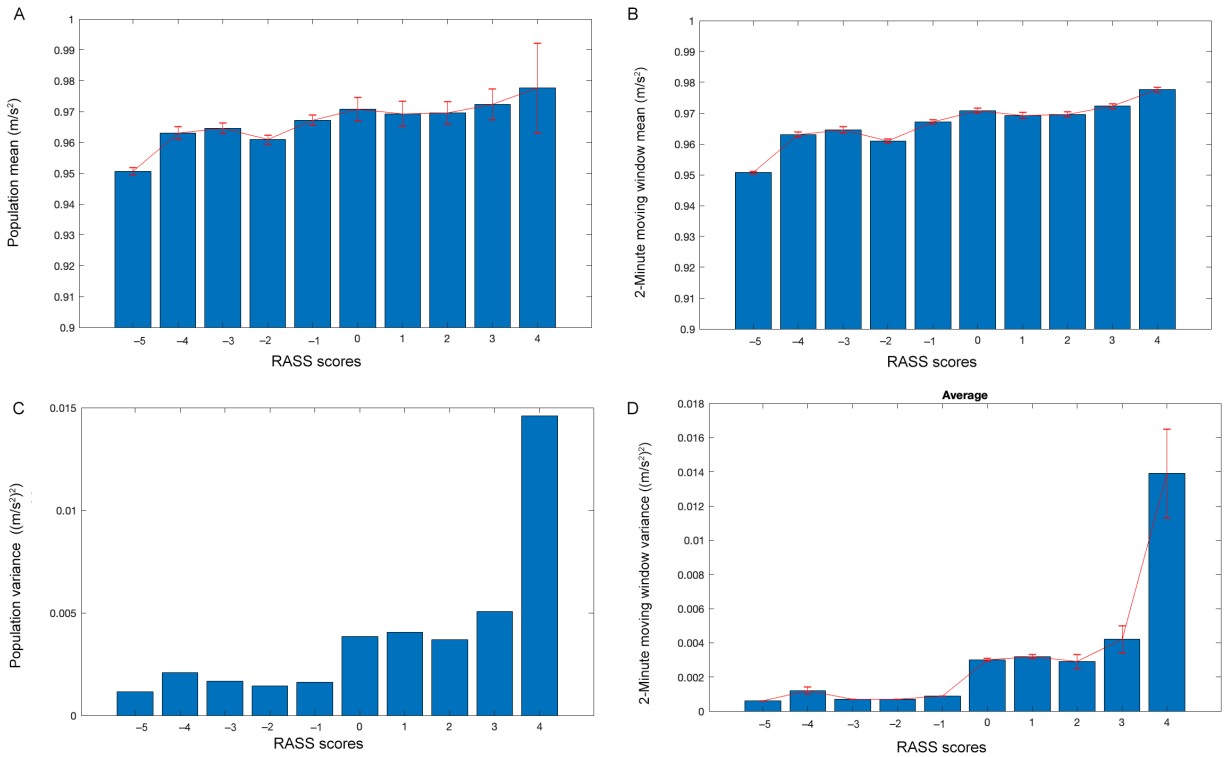


Figure 3. Population mean acceleration at a given Richmond Agitation and Sedation Scale (RASS) score (with variance) (A). Average 2-minute moving window mean at a given RASS score (B). Overall population variance at a given RASS score (C). Average 2-minute moving window variance at a given RASS score (D)



Results

We studied 20 patients for a mean of 9.7 hours (interquartile range [IQR], 0–22.8) and a total of 160 hours. The period of recording was from early evening until late the following morning. The baseline characteristics as clinically assessed at the time of enrolment are presented in the online Appendix, table 1.

Video-assisted assessment of sedation

Figure 1 shows a frequency histogram of all 8294 video-assisted assessments of RASS scores. Forty-one per cent of all patient observations revealed RASS scores that fell within the routinely prescribed range of –2 to 0. During continuous RASS assessment, 39% of patients were excessively sedated and 20% were inadequately sedated.

Accelerometry

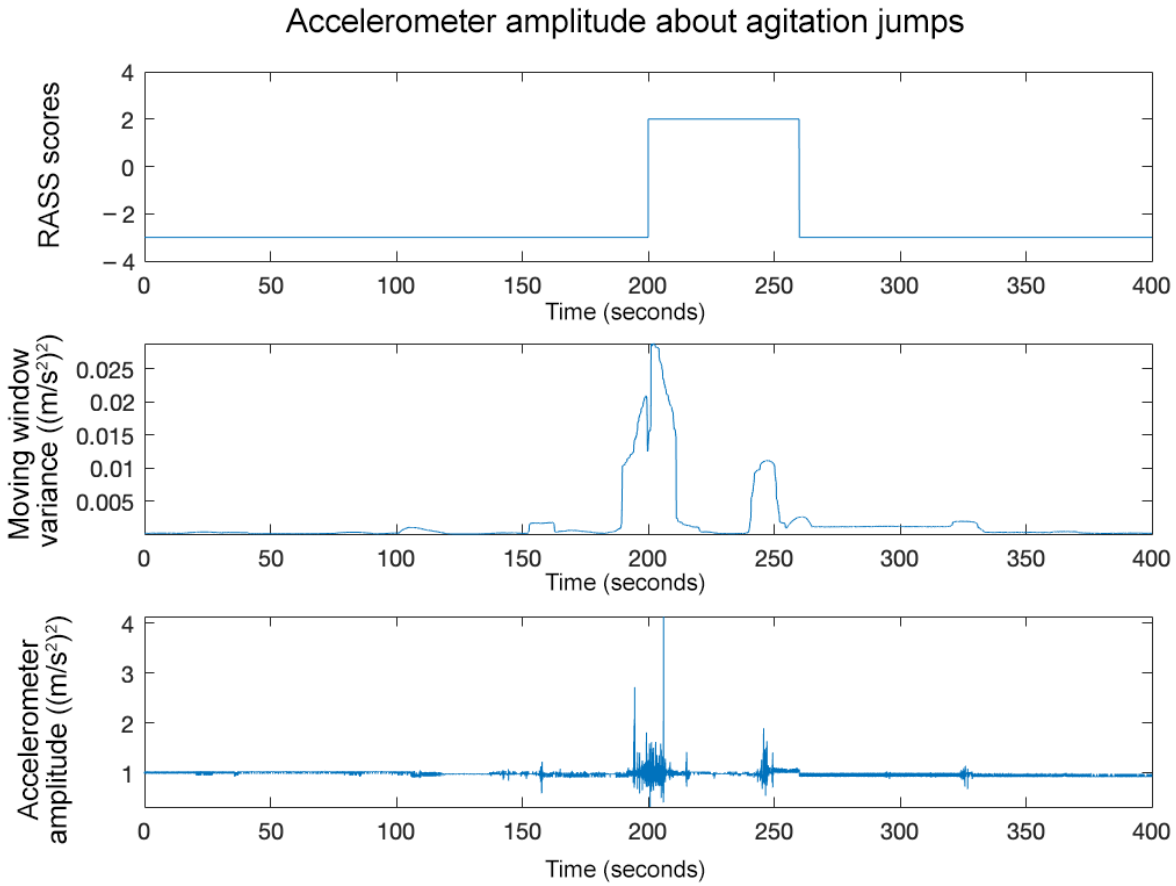
Sample recordings of accelerometry amplitudes versus time at three different RASS scores are shown in Figure 2. We obtained an average 4 625 700 discreet accelerometry values (IQR, 0–10 910 700) for each individual RASS score.

Figure 3 shows the accelerometry raw and derived values at a given RASS score; data for this table are provided in the online Appendix, table 2. The average population mean and variance, moving window mean, and moving window variance across both wrists are shown in Figure 3. An increasing RASS score was associated with consistent increases in all variables. Agitation produced a larger absolute increase in variance than sedation. This reflected the increasing magnitude of variability of movement observed with increasing patient agitation and smaller absolute differences in motor variability across with increasing levels of sedation.

Anticipation of increases in RASS score

Across 160 hours of recording, 340 discreet events were observed in which the RASS score increased by at least 2 points in consecutive 30-second epochs. An example of two consecutive such events in a single patient is depicted in Figure 4. All 340 events were analysed and the 2-minute moving window mean and variance were calculated for 10 minutes before and 5 minutes after each event (Figure 5). Increasing RASS score was associated with a distinct and discreet preceding spike in moving window accelerometry variance as the patient emerged from sedation.

Figure 4. An example of a patient's data showing Richmond Agitation and Sedation Scale (RASS) scores, acceleration, and moving window variance over about 10 minutes. A patient is observed to transition from across a range of RASS scores. The accelerometry power output is depicted in the middle graph and the 30-second moving window variance on top. The amplitude is proportional to the RASS score and the moving window variance presages an increase in agitation



Discussion

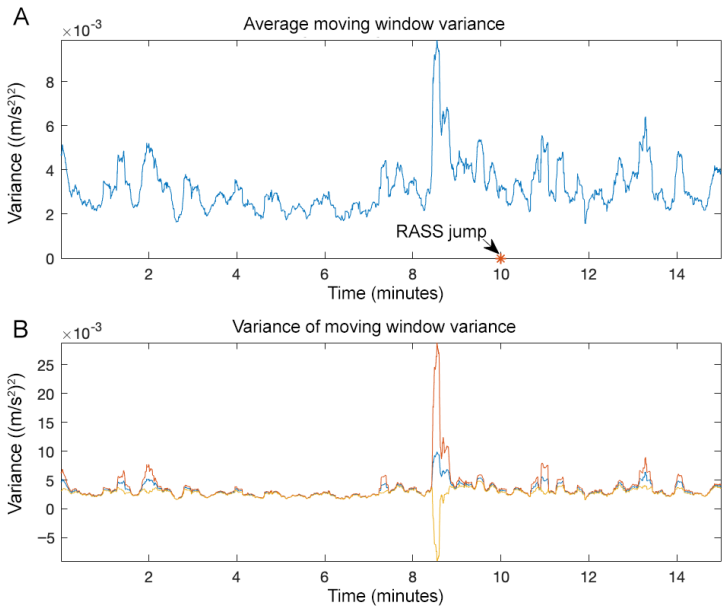
Key findings

We conducted a prospective, observational pilot study of accelerometry in ICU trauma patients experiencing different levels of sedation and agitation. We found that bilateral wrist accelerometry was easily implemented and provided novel information about patient behaviour in a continuous manner. Using continuous accelerometry and video surveillance, we found a promising and consistent relationship between RASS and wrist accelerometry. The magnitude of accelerometry moving window variance appeared particularly closely correlated with the RASS score. The variance of variance was associated with an impending increase in RASS score.

Relationship to previous studies

Accelerometry-based electronic motion detectors have been trialled for a variety of applications in the ICU. They have been used to monitor cardiopulmonary resuscitation quality[15] and have been investigated as a means of measuring energy expenditure,[16,17] assessing ICU sleep quality,[18,19] and quantifying recovery of mobility after surgery.[20,21] In the general inpatient setting, they have been accurate at detecting seizures.[22] In geriatric inpatients, the intensity of accelerometer-measured motor activity has been shown to be higher in hyperactive than in hypoactive delirium.[23] Efforts to classify delirium using accelerometry have also been made in the palliative care setting.[24] Physical activity after ICU discharge has been investigated using accelerometers in smartphones, FitBit pedometers (FitBit,

Figure 5. Mean variance in acceleration around a jump in the Richmond Agitation and Sedation Scale (RASS) score of at least 2 points (A), with standard deviation (B)



San Francisco, USA), and the ActiGraph device.[25-29] The wrist is superior to the ankle at detecting clinically significant movement in the ICU.[30]

Wrist-based accelerometry to measure sedation and agitation in the ICU has previously been described.[6] This was a larger study of 86 patients which utilised the ActiGraph device placed on the non-dominant wrist and used the device's simple tally of movements above a threshold of intensity to correlate with a five-point agitation–sedation scale every 10 minutes. Our study concurred with this finding and showed similar increases in accelerometry signal with increasing agitation. With a greater resolution in both accelerometry and high frequency RASS assessment, we were able to explore this correlation in much greater granularity. Further, using this approach we were, for the first time, able to observe the phenomenon of rapidly increasing RASS scores with accelerometers sufficiently sensitive to record variability of movement.

Study implications

Our study implies that accelerometry can be successfully deployed in the ICU even in patients with trauma who may experience agitation. Moreover, our findings imply that accelerometry may represent a technique for the objective and continuous monitoring of time spent in the target sedation range and thus estimate the quality of sedation. Finally, our observations imply that this technique shows promise as a means of alerting staff to impending agitation and heralding awakening. Such ability to predict imminent transition phases may allow for more precise, timely and safe sedation administration.

Study strengths and limitations

The strengths of our approach include employment of high frequency accelerometry, simultaneous bilateral wrist recordings, long recording periods, detailed accounting for movement artefact through identification of potential confounding passive movements, and high frequency video assessment of the RASS. In all, nearly 20 000 individual RASS scores were assessed. The techniques allowed higher resolution assessment of accelerometry than has been previously used in the ICU. We demonstrated that inferences about RASS scores can be made from patient movement and, for the first time, we also attempted to anticipate impending emergence from sedation. Moreover, the potential utility of these analysis techniques is that they have the potential to be deployed clinically in real time as they only require retrospective data. Our study has demonstrated the methodological utility of studying wrist-based accelerometry with frequent high fidelity video assessment of RASS in the ICU. Our methodology supports further study of a technique that enables both continuous and predictive sedation monitoring.

Our study was limited by a small population of patients despite observing them over long recording periods. A consequence of this was that we were unable to quantify differences in the ability of the left and right wrists (or their combination) with RASS data. Furthermore, we cannot comment on the non-trauma ICU population and would need to examine a broader cross-section of ICU patients before being able to comment on the technique's generalisability to all ICU patients. Another limitation of our study was our inability to correlate our data with changes in sedative medication dosing. These are aggregated across hourly intervals in our ICU nursing record, and the pharmacokinetics of propofol (the primary sedative drug used) are such that the effects of changes in sedation are seen over much shorter periods. Ideally, future data would be captured continuously to allow for cross-referencing with motor and sedative dosage changes.

Conclusions

In this exploratory study of accelerometry in ICU trauma patients, we describe a method of accelerometry signal analysis that showed a consistent relationship with the RASS. We also describe a phenomenon and a method of analysis using accelerometry that can be used to identify and herald an impending increase in RASS score. Our findings imply that accelerometry may represent a technique for the objective and continuous monitoring of time spent in the target sedation range, for the measurement or audit of the quality of sedation, and for alerting staff to impending agitation. These preliminary findings provide the rationale for the performance for further observational studies and pilot randomised controlled trials of accelerometry versus RASS-guided sedative therapy in the ICU.

Competing interests

None declared.

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