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Vital signs fluctuations and their relationship with pain in the brain-injured adult critically ill – A repeated-measures descriptive-correlational study ☆

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ABSTRACT

Objectives: To evaluate the use of vital signs for pain detection in brain-injured patients in the intensive care unit.
Design: A repeated-measures descriptive-correlational study.
Setting: Two neurological intensive care units in Montréal, Canada. A total of 101 brain-injured patients were included.
Main outcome measures: This study examined the fluctuations in systolic and diastolic blood pressure, heart and respiratory rates, and oxygen saturation in brain-injured critically ill patients before, during, and 15 minutes after turning and soft touch using a data collection computer. When possible, patients' pain self-reports were obtained using a 0–10 Faces Pain Thermometer.
Results: The heart and respiratory rates were higher during turning than soft touch and higher during the procedure compared to prior ($p < 0.05$), but their fluctuation was modest. The systolic blood pressure increased during both turning and soft touch by 2 mmHg, but was 26.6 mmHg higher for those who reported pain versus no pain (Mann-Whitney = 25.00, $p = 0.008$, $n = 28$). A moderate correlation was observed between the systolic blood pressure (Spearman's rho = 0.617, $p = 0.004$, $n = 24$) and self-reported pain intensity during turning. No significant effects were observed for diastolic blood pressure and oxygen saturation.
Conclusion: Only increases in systolic blood pressure were positively associated with pain in this sample and replication studies with larger samples is needed.

Implications for Clinical Practice

- Only heart and respiratory rates were significantly higher during turning compared to soft touch, but their fluctuation was modest.
- Increases in the systolic blood pressure were positively associated with pain and may be used as a cue for further assessment of pain using appropriate valid methods.
- Behavioral scales remain the best available alternative measures for pain detection in the non-verbal brain-injured critically ill.

☆ This study was conducted at the Montreal Neurological Institute and Montreal General Hospital in Montréal, Canada.

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Introduction

The intensive care unit (ICU) involves the close observation of patient's health status including fluctuations in vital signs, which are easily accessible using bedside monitoring. Given the common challenges in obtaining the brain-injured ICU patient's self-report of pain due to the altered level of consciousness (LOC), cognitive or language deficit and the use of sedation (Schnakers and Zasler, 2015; Young, 2007; Yu et al., 2013), many nurses rely on fluctuations in vital signs to detect the presence of pain. One large survey with 842 nurses indicated that >70% of them used vital signs alone or in combination with behaviors, to assess pain in non-verbal ICU patients (Rose et al., 2012). Whereas the use of vital signs for pain detection in adult medical-surgical ICU patients received little empirical support (Gélinas, 2016), not much is known with regards to their utility for pain assessment in the brain-injured ICU adults. When compared to medical-surgical ICU patients, those with a brain injury showed the highest variations in vital signs (Gélinas and Arbour, 2009), calling forth the need to further explore the role of vital signs for pain detection in this patient group.

One study with 45 ICU patients with a traumatic brain injury (TBI) found the respiratory rate (RR) to have discriminative properties across turning (i.e., nociceptive) and non-invasive blood pressure taking (i.e., non-nociceptive), but failed to correlate with self-reported pain intensity from 12 patients (Arbour et al., 2014). Similar results were observed with 43 ICU patients post brain surgery who experienced an average increase in RR of 13 breaths per minute during turning compared to non-invasive blood pressure taking (Kapoustina et al., 2014). No correlations were observed between any of the vital signs and self-reported pain intensity. Similarly, in a large study in which 214 brain-injured ICU patients with various diagnoses (i.e., postoperative for brain tumors, stroke, TBI), heart rate (HR) and mean arterial pressure (MAP) could adequately classify only 64% and 59% of patients who reported pain versus no pain during endotracheal suctioning (Shan et al., 2018). Given the inconclusive results regarding the validity of vital signs for pain detection in brain-injured ICU patients, more research is needed to verify if monitoring for fluctuations in vital signs can assist nurses in this difficult endeavor.

Objectives

This study aimed to validate the use of vital signs (Systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), RR and oxygen saturation (SpO2) for pain detection in brain-injured adult ICU patients. The specific objectives were to examine:

1. The ability of vital signs to discriminate between different assessment periods (before, during, 15 minutes later) and procedures (soft touch and turning) (i.e., discriminative validation).
2. The association of vital signs with the gold standard measure of pain i.e., the patient's self-report of pain (i.e., criterion validation) during turning.

Given the mixed findings observed to date and the few research studies in this population, no a priori hypotheses were formulated.

Methods

Study design

A repeated-measures descriptive-correlational study design was used to examine the fluctuations in vital signs for a cohort of patients across two procedures (i.e., nociceptive and non-nociceptive) and three consecutive time points (i.e., before, during, and 15 minutes after each procedure). This study was conducted in the context of a larger project that also aimed to validate behavioral indicators of pain in brain-injured adult ICU patients and those results are reported elsewhere (Gélinas et al., 2019).

Setting and ethical approval

This study was conducted in two university-affiliated hospitals in Montréal, Canada who approved the procedures of this study. Recruitment started in June 2013 and ended in December 2014. Data collection started after obtaining informed consent and was completed within 24 hours.

Participants

Patients were eligible if they were: 1) 18 years and older, 2) in the ICU for <4 weeks following TBI (with polytrauma or not) or non-traumatic brain injury, and 3) had Glasgow Coma Scale (GCS) (Teasdale and Jennett, 1974) score >3. Patients were excluded if they: 1) sustained spinal cord, brainstem, or cerebellar injury or had peripheral neuro-pathologies, 2) were diagnosed with cognitive deficits, psychiatric conditions (e.g., depression) or epilepsy, 3) had a previous TBI or stroke, 4) were receiving neuromuscular blocking agents and 5) were suspected for brain death. The exclusion criteria were based on the larger study to eliminate potential confounders with behavioral indicators of pain (e.g., neuromuscular blocking agents or paralysis precluding expression of behaviors).

The sample size was initially determined based on the power requirements for the larger study to detect changes in behaviors during a nociceptive procedure with a correlation of 0.30 between procedures, power of 90% and alpha of 0.01 for repeated-measures analysis of variance (RM-ANOVA) (Gélinas et al., 2019). The sample included in this study (n = 101) led to a power > 99% to run RM-ANOVA for fluctuations in vital signs. In order to reach a minimal moderate correlation of 0.50 (with a level of significance of 0.05 and a power of 80%) between vital signs and self-reported pain intensity, a sample of 29 patients able to self-report was needed (G*Power) (Faul et al., 2009). Patients were recruited using convenience sampling.

Data collection

The ICU assistant nurses and clinical educators screened and approached eligible patients for participation. If patients or their representatives expressed interest in the study, research staff explained the study procedures and obtained written consent. When patients presented with an altered LOC, written consent was obtained from the representative who was consenting for the patient's care.

After obtaining written consent, the research staff collected socio-demographic and clinical data from the patients' medical records. A data collection computer (CNS monitor Model 100, Moberg Research Inc.) was connected to the bedside monitor using a serial port cable for the continuous monitoring of vital signs. For the larger study, a video camera was installed in the room to record behaviors during procedures. The research staff marked the specific assessments events on the data collection computer: at rest before, during and 15 minutes after each procedure. No adjustments in adrenergic or vasoactive medications were made during data collection. When possible, patients were asked to self-report their pain right after turning, one of the most painful routine ICU procedures (Puntillo et al., 2014, Puntillo et al., 2001) and soft touch. Turning was performed by the ICU staff (i.e., nurses and orderlies) as part of the standard ICU care. The three-step procedure involved using the log-roll technique for turning patients from their resting supine position to lateral decubitus (90 degrees), back to supine, to the opposite lateral decubitus position (90 degrees) and finally, supine. The ICU staff were not instructed to modify their approach for the turning procedure and to proceed as per the standard of ICU care.

Soft touch (i.e., placing the two hands of the research staff on the patient's forearm for one minute) was used as the non-nociceptive procedure as described by Li and colleagues (2009).

Outcomes and measurement

Socio-demographic and clinical data

Socio-demographic data such as age, gender and ethnicity were collected from the patients' medical records. The GCS was used to document patients' LOC (Teasdale and Jennett, 1974), the Richmond Agitation Sedation Scale (RASS) for the level of sedation (Sessler et al., 2002) and the Confusion Assessment Method for the ICU (CAM-ICU) for the presence of delirium (Ely et al., 2001b). The use of mechanical ventilation, analgesia and sedation administration were recorded.

Vital signs

Vital signs (i.e., SBP, DBP, HR, RR, SpO2) were recorded continuously by the patients' bedside monitors using intra-arterial sensors and electrocardiogram electrodes. The data collection computer was connected to the ICU monitor to collect vital signs fluctuations at 1-second interval for each assessment point. The means of vital signs for 1 minute were used in data analysis.

Pain intensity

Immediately after turning and soft touch, and when possible, patients were first asked to indicate if they had experienced pain during the procedure by responding *yes* or *no* verbally, or through gestures such as head nodding, hand squeezing or blinking. Then, they were asked to self-report their pain intensity using the 0–10 Faces Pain Thermometer (FPT) (Gélinas, 2007). The FPT consists of a thermometer graded from 0 for no pain to 10 for maximum pain intensity along with six faces adapted mainly from the work of Prkachin (1992), and was successfully used in other validation studies with brain-injured ICU patients (Arbour et al., 2014; Kapoustina et al., 2014).

Data analysis

Descriptive statistics were calculated for sociodemographic and clinical data. This study used the available case analysis approach by using pairwise deletion for missing data. Discriminative validation (i.e., the ability of vital signs to discriminate nociceptive from non-nociceptive procedures (Gélinas et al., 2008) was examined using the two-way repeated measures ANOVA. The Greenhouse-Geisser correction was used when the Mauchly's Test of Sphericity was statistically significant (Tabachnick and Fidell, 2013). Criterion validation (i.e., vital sign's correlation to the gold standard, the patient's self-report of pain) was evaluated using the Mann-Whitney test between those reporting the presence of pain and those negating pain during turning, and the Spearman's rho correlation coefficient between mean fluctuations in vital signs and pain intensity scores given the skewed distributions of pain self-reports.

Results

A total of 147 patients were approached, of which 27 patients/representatives refused (Supplemental Digital Content 1) and 120 consented. A total of 101 patients were included. Half of patients were admitted in the ICU following non-traumatic brain injury (i.e., stroke) (n = 52, 51%), the majority were male (n = 66, 65%) and had a median age of 56 years (Table 1). Based on the RASS (Sessler et al., 2002), most patients were lightly sedated (−2) before each procedure; 27 received concomitant analgesia and sedation, 11 sedation and 7 analgesia only (Supplemental Digital Content 2). None of the participating patients had hemiplegia at the time of data collection.

Discriminative validation

The Greenhouse-Geisser estimates were reported to adjust for the violation of the assumption of sphericity (Mauchly test, $p < 0.05$). The two-way repeated-measures ANOVA showed significant effects for the fluctuations in HR and RR during the procedure (turning and soft touch), time of assessment (before, during, 15 min later) and interaction (procedure × assessment) (Table 2). HR and RR were higher during turning than soft touch, and higher during the procedure compared to prior ($p < 0.05$), but with modest differences ranging from one to two beats and breaths per minute, respectively. A significant time effect was observed for fluctuations in SBP which was 2.14 mm Hg higher during the procedure (i.e., turning, soft touch) compared to prior, and 2.68 mm Hg higher post compared to pre-procedure ($p < 0.05$). No significant effects were observed for fluctuations in DBP and SpO2.

Criterion validation

From the 48 conscious patients, 28 patients could report the presence/absence of pain and 24 patients were able to quantify pain intensity on the 0–10 FPT. From these 28 patients, sixteen (57%) denied experiencing pain, and those able to quantify the severity of pain (n = 24) reported a median of 0 (range 0–8) during

Table 1
Sociodemographic and clinical data for the adult brain-injured intensive care unit patients (n = 101).

Variables	Descriptive Statistics
Age (median, range)	56 (18–89)
Gender (n, %)	
Male	66 (65%)
Female	35 (35%)
Ethnicity (n, %)	
Caucasian/White	80 (79%)
First Nation	8 (8%)
African American/Black	4 (4%)
Hispanic	4 (4%)
Missing	5 (5%)
Diagnosis (n, %)	
Non-Traumatic Brain Injury	52 (51%)
Aneurysm	33 (32%)
Embolic Stroke	18 (18%)
Brain Abscess	1 (1%)
Traumatic Brain Injury	49 (49%)
Level of Consciousness (Glasgow Coma Scale) (n, %)	
Unconscious (GCS < 8)	19 (19%)
Altered (9 < GCS < 12)	34 (34%)
Conscious (13 < GCS < 15)	48 (47%)
Glasgow Coma Scale (median, range)	10 (4–15)
Richmond Agitation-Sedation Scale (median, range)	−2 (-4 to 3)
Confusion Assessment Method for the Intensive Care Unit (n, %)	
Positive	5 (5%)
Negative	23 (23%)
Not Evaluable	73 (72%)
Mechanically Ventilated (n, %)	
Yes	54 (53%)
No	47 (47%)
Analgesia and Sedation within 4 h of data collection (n, %)	
Analgesia only	7 (7%)
Sedation only	11 (11%)
Concomitant analgesia and sedation	27 (27%)

Table 2
Discriminative validation of vital signs fluctuations across nociceptive (i.e., turning) and non-nociceptive (i.e., soft touch) procedures using two-way repeated measures analysis of variance.

Vital Signs	Independent Variable	N	F Statistic	Significant Post hoc Comparisons (p < 0.05)	Mean Difference	Partial Eta Squared	Observed Power
Systolic Blood Pressure	Procedure	74	0.230			0.003	0.076
	Time		3.925*	During procedure > pre-procedure	2.14 mmHg	0.131	0.832
	Procedure X Time		3.232	Post-procedure > pre-procedure	2.68 mmHg	0.110	0.745
Diastolic Blood Pressure	Procedure	74	0.335	–	–	0.005	0.088
	Time		1.450			0.086	0.620
	Procedure X Time		2.185			0.094	0.666
Heart Rate	Procedure	83	4.216*	Turning > soft touch	1.11 bpm	0.049	0.528
	Time		4.508*	During procedure > pre-procedure	1.26 bpm	0.175	0.963
	Procedure X Time		8.692*			0.221	0.992
Respiratory Rate	Procedure	67	33.50*	Turning > soft touch	2.03 brpm	0.337	1.00
	Time		9.11*	During procedure > pre-procedure	1.50 brpm	0.344	1.00
	Procedure X Time		21.18*	During procedure > post-procedure	1.43 brpm	0.379	1.00
Oxygen Saturation (SpO2)	Procedure	73	3.901	–	–	0.051	0.496
	Time		1.462			0.044	0.332
	Procedure X Time		1.120			0.032	0.249

Abbreviations: *bpm*, beats per minute; *brpm*, breaths per minute.
*p < 0.05.

turning. The median pain intensity on the 0–10 FPT for those reporting pain was 4.5 (range 1–8, n = 10), and those negating pain reported 0 pain intensity on the 0–10 FPT (n = 14). The only statistically significant difference in vital signs between those reporting and those negating pain during turning was the SBP (Mann-Whitney = 25.00, p = 0.008), which was 26.6 mmHg higher for those in pain. A moderate correlation was observed between the SBP (Spearman's rho = 0.617, p = 0.004) and patients' self-report of pain intensity during turning. Low non-significant correlations were noted between pain intensity and the other vital signs, namely DBP (Spearman's rho = 0.316, p = 0.175), RR (Spearman's rho = 0.281, p = 0.206), HR (Spearman's rho = 0.255, p = 0.253) and SpO2 (Spearman's rho = 0.262, p = 0.294).

Most patients able to self-report (79%) rated pain intensity during soft touch as 0 on the 0–10 FPT with a median of 0 and scores ranging from 0 to 4.

Discussion

This study supports some validation properties of HR, RR and SBP for pain assessment in brain-injured ICU patients, however, fluctuations in vital signs were inconsistent and may be a consequence associated with the brain injury. In this study, the SBP, HR and RR increased significantly during procedures compared to prior, but the mean difference between these two assessment points was modest. The HR and RR could also discriminate a nociceptive from a non-nociceptive procedure, thereby supporting their discriminative properties with the brain-injured ICU patients. Although the SBP increased by approximately 2 mmHg during compared to pre-procedure, this significant time effect was present regardless if the procedure was nociceptive or not, suggesting that even tactile stimulation in the form of soft touch can trigger a mild increase in SBP. In previous ICU studies, inconsistent findings have been found. In a study by Ribeiro et al. (2017) with 20 mechanically ventilated TBI patients, HR and DBP did not show significant increases during endotracheal suctioning, only SBP was significantly higher. On the other hand, the same research team found significant increases in HR (26 beats/min), SBP (14 mmHg) and DBP (13 mmHg) during endotracheal suctioning in 37 mechanically ventilated TBI patients (Ribeiro et al., 2019). In another study with 45 TBI patients, HR and blood pressure parameters (i.e., SBP, DBP, MAP) increased during both the nociceptive and the non-nociceptive procedures, but RR was higher exclusively during turning compared to non-invasive blood pressure (Arbour et al., 2014). Therefore, the evidence does not consistently support the discriminative ability of vital signs for the detection of pain as they may vary during any type of procedure (nociceptive versus non-nociceptive) (Gélinas, 2016).

Only 28 brain-injured ICU patients (28%) could report the presence or absence of pain either verbally or through gestures, and even less (n = 24, 24%) could quantify pain intensity from 0 to 10. Of note, some patients experienced delirium during data collection (n = 5) as per the CAM-ICU (Ely et al., 2001b) and provided questionable self-reports of pain presence and intensity. Delirium is frequently unrecognized in the ICU given that it is commonly manifested in the hypoactive form (Ely et al., 2001a,b; Pandharipande et al., 2008). The use of the CAM-ICU (Ely et al., 2001b) for delirium detection in the neurologically critically ill remains challenging due to the difficulty in differentiating it from symptoms of the underlying neurological pathology (Gélinas et al., 2018; Gélinas et al., 2013; Yu et al., 2013). Regardless if patients' self-reports were reliable or not, these patients represent only half of all the conscious patients (n = 28/48), which suggests that having an altered LOC is only one, of the multiple factors behind the inability to self-report. Such findings highlight the vulnerability of these patients to have their pain unrecognized and call forth the need to use valid tools for pain assessment in brain-injured ICU patients.

The SBP correlated moderately with pain intensity during turning and was significantly higher for those reporting pain compared to those pain-free, although this was observed for a small sample. Increases in SBP may be related to the presence of pain, but future studies with larger samples of patients able to self-report are needed to confirm this. Until then, increases in SBP may be used as a cue for further assessment of the presence of pain with appropriate valid methods. Nonetheless, alterations in vital signs such as increases in SBP are not generalizable to severe brain-injured patients unable to self-report for whom it could indicate a poor prognosis (Gregory and Smith, 2012; Rizoli et al., 2017), and could also indicate a hyperdynamic cardiovascular state secondary to the brain injury itself (Tahsili-Fahadan and Geocadin, 2017). The use of vasopressors could equally be a factor influencing blood pressure values, and is common treatment to raise cerebral perfusion pressure in TBI patients (Sookplung et al., 2011).

Among the patients able to self-report, the majority reported no pain during turning with a median of 0 pain intensity on a 0–10 FPT. These results are lower than what was observed during the same procedure with brain-injured ICU patients of mixed diagnoses (median = 8, range 1–10, n = 17) (Joffe et al., 2016) and post elective brain surgery (mean = 3.08, SD = 3.41, n = 41) (Kapoustina et al., 2014). As seen on videos, the "log roll" technique used during turning for this population of ICU patients might have contributed to less pain given the enhanced body alignment and stabilization during this procedure, although the prevalence of pain in the patients who were unable to self-report (72%) could not be estimated.

Clinical implications

Only heart rate and respiratory rate could discriminate between the nociceptive and the non-nociceptive procedures in this study, and systolic blood pressure was found to increase during both types of procedures. Very few patients could self-report and results regarding the criterion validation of vital signs for pain assessment are rather preliminary. Consistent with practice guidelines (Devlin et al., 2018) and professional associations' position papers (Gélinas and Puntillo, 2018; Herr et al., 2011), the study findings do not support the use of vital signs and behavioral scales such as the Critical-Care Pain Observation Tool (Gélinas et al., 2006; Joffe et al., 2016) and the Behavioral Pain Scale (Payen et al., 2001) remain the best available alternative measures to self-report for pain assessment in the non-verbal brain-injured ICU patients.

Limitations

Many conscious patients were unable to self-report pain, and larger studies are needed to reach more brain-injured ICU patients who can self-report to examine the relationship between self-report and vital signs fluctuations. RR was recorded using electrodes of the electrocardiogram whose sensitivity may be diminished during turning and future studies could use the mechanical ventilator when available. The presence of artefacts led to missing data for all vital signs but allowed adequate power for most interaction effect analyses except for SpO2. The turning procedure was performed as part of standard ICU practice and could not be standardized. The soft touch procedure was used as described in previous studies (Li et al., 2009; Ross et al., 2016) but could have led to different perceptions by patients, however, the majority (79%) rated soft touch as non-painful (score of 0/10) supporting its non-nociceptive nature.

Conclusion

This study supports the discriminative validation of the HR and RR for pain assessment in brain-injured adult ICU patients, however, their increases were modest. A moderate correlation between patients' self-reports of pain intensity and SBP was noted during the nociceptive procedure, yet future studies with a larger sample of patients able to self-report are needed. Until then, behavioral scales remain the best available alternative measures for pain detection in the non-verbal brain-injured critically ill.

CRediT authorship contribution statement

Madalina Boitor: Writing - review & editing. **Mélissa Richard-Lalonde:** Writing - review & editing. **Mélanie Bérubé:** Writing - review & editing. **Gosselin Émilie:** Writing - review & editing. **Céline Gélinas:** Writing - review & editing.

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Declaration of Competing Interest

None.

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Ethical approval

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.iccn.2019.07.002.

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