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ORIGINAL RESEARCH

Pulmonary

Assessment of respiratory rate monitoring in the emergency department

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Abstract

Objectives: This study aimed to compare the different respiratory rate (RR) monitoring methods used in the emergency department (ED): manual documentation, telemetry, and capnography.

Methods: This is a retrospective study using recorded patient monitoring data. The study population includes patients who presented to a tertiary care ED between January 2020 and December 2022. Inclusion and exclusion criteria were patients with simultaneous recorded RR data from all three methods and less than 10 min of recording, respectively. Linear regression and Bland–Altman analysis were performed between different methods.

Results: A total of 351 patient encounters met study criteria. Linear regression yielded an *R*-value of 0.06 (95% confidence interval [CI] 0.00–0.12) between manual documentation and telemetry, 0.07 (95% CI 0.01–0.13) between manual documentation and capnography, and 0.82 (95% CI 0.79–0.85) between telemetry and capnography. The Bland–Altman analysis yielded a bias of −0.8 (95% limits of agreement [LOA] −12.2 to 10.6) between manual documentation and telemetry, bias of −0.6 (95% LOA −13.5 to 12.3) between manual documentation and capnography, and bias of 0.2 (95% LOA −6.2 to 6.6) between telemetry and capnography.

Conclusion: There is a poor correlation between manual documentation and both automated methods, while there is relatively good agreement between the automated methods. This finding highlights the need to further investigate the methodology used by the ED staff in monitoring and documenting RR and ways to improve its reliability given that many important clinical decisions are made based on these assessments.

KEYWORDS
capnography, respiratory rate, telemetry

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1 | INTRODUCTION

1.1 | Background

Respiratory rate (RR) is a core vital sign used to monitor every patient in the emergency department (ED). It is well established that monitoring RR is more challenging because it is associated with more variability and errors in measurement compared to other vital signs.[1–3] Currently, in clinical practice, there are three main methods of monitoring RR—manual, telemetry, and capnography. The manual method involves counting the number of breaths by observing the patient and is typically associated with human error and is often affected by misreporting as well as Hawthorne effect.[4] The telemetry method is part of patient monitors typically used in the clinical environment, and it measures RR by either detecting thoracic impedance changes or analyzing the electrocardiographic waveforms. Telemetry is currently the standard method of monitoring RR in clinical settings. Lastly, capnography measures RR from directly detecting the end-tidal carbon dioxide ($EtCO_2$) using a specialized nasal cannula. Since capnography is based on directly detecting respiration, it is the most accurate method and considered to be the gold standard of RR measurement.[5] However, capnography is typically used only in cases where close respiratory monitoring is required.

1.2 | Importance

Respiratory rate is one of the most important vital signs in the assessment of a patient's clinical status.[6] This is true not only for patients with primarily respiratory illness, but also for those with nonrespiratory illnesses such as sepsis and shock. Since respiration is the body's primary way of compensating for acidosis in acute settings, a patient's RR serves as an early detector of systemic illness as well as a predictor of negative outcomes such as cardiac arrest and ICU admission or transfer.[6–10] Even in relatively lower acuity patients being discharged from the ED, studies have shown increased rates of deterioration in patients with increased RR at the time of discharge.[11] For these reasons, it is crucial that reliable RR monitoring is performed so that adequate and timely intervention is provided. In addition, it is important to note that the documentation of RR in a patient's chart is typically performed manually rather than imported automatically from the monitor due to errors associated with the automated methods.[12,13] While this manual process is necessary, it introduces various sources of potential error and bias such as the ED staff's opinion on the accuracy of the automated methods and their subjective assessment of patient's clinical status.[14] Given that important clinical decisions are frequently made based on the manually documented RR in the patient's chart, quality assurance of documented RR is essential.

1.3 | Goals of this investigation

A few prior studies have evaluated the reliability of RR monitoring in ED triage settings.[12,15] However, to our knowledge, there is no study that has evaluated the reliability of RR monitoring throughout the ED stay. Since many important clinical decisions including interventions and determination of dispositions rely on RR monitored throughout the patient's ED stay, it is important to understand the reliability of the documented RR. Therefore, the goal of this study is to compare the different RR monitoring methods used in the ED, namely, (1) manual documentation, (2) telemetry, and (3) capnography by utilizing RR data collected during the ED stay.

The Bottom Line

In this study of 346 patients, Lee et al address the accuracy of respiratory rate (RR) monitoring for patients already admitted to the emergency department (ED). Manual RR's level of agreement with RR's determined by telemetry or capnography exceeded ±10 breaths/minute with divergent results in 80–90% patients with tachypnea. This could lead to inaccurate results for commonly used scoring systems and more directly lead to acute over or under-treatment.

2 | METHODS

2.1 | Study design and setting

This is a retrospective study performed at Beth Israel Deaconess Medical Center (BIDMC) (Boston, MA) utilizing electronically captured data. BIDMC is a tertiary care center with an annual ED census of approximately 52,000 patients per year. Data capture was performed using a hospital proprietary electronic medical record (EMR), which systematically records and archives various electronic monitoring data from the ED patients. The study was approved by BIDMC committee for clinical investigations under a waiver of informed consent.

2.2 | Selection of participants

The study population included all patients who presented to the ED between July 2020 and December 2022. The inclusion criterion was the presence of simultaneous RR recordings from (1) manual documentation, (2) telemetry, and (3) capnography. Exclusion criterion was less than 10 min of either telemetry or capnography recording data as this was deemed to be insufficient for analysis. The rationale for selecting patients who were on both telemetry and capnography was to address the challenge of obtaining a ground truth measurement. While capnography is considered to be the most accurate method,[16] it is still not reliable enough on its own without human oversight. Previous work has addressed this issue by having a provider or a research staff at the bedside to ensure accurate measurement,[17] but this can affect the patient's behavior as well as the way the ED staff perform

manual documentation. By selecting patients with measurements from two automated methods and a manual method, we can assess agreement between the methods as well as attempt to deduce accuracy. In addition, by selecting the patients who are on capnography, the study focuses on those who are at a higher risk of decompensating given that capnography is typically used for those who need closer respiratory monitoring. While this group of patients is not representative of the general ED patient population, they represent those who need more accurate and reliable RR monitoring, and therefore are more pertinent to this study.

2.3 | Data collection

Data collection was performed by querying the EMR for all ED encounters meeting the study criteria. The EMR records RR from telemetry and capnography at 1-min intervals in addition to storing the RR manually entered by the ED staff. In the BIDMC ED, manual documentation occurred per routine clinical practice. It is important to note that these recorded RRs were documented during the patient's stay in the department and were not part of the triage vital signs.

2.4 | Data analyses

For every time point for manually documented RR, corresponding time points were identified for telemetry and capnography. To remove data points that were obviously affected by measurement error, we assessed the stability of the recoding by selecting a short segment around the time point and calculating the coefficient of variation (CV), defined as the ratio of the standard deviation (SD) to the mean of the segment. Physiologically, RR over a short period of time (ie, minutes) should not vary significantly.[18] Therefore, a large CV suggests that the recording is unstable due to measurement error rather than a real variation in RR. Therefore, if the CV was below a predefined threshold, the mean of the segment rounded to the nearest whole number was used as the representative RR. In this work, a segment length of 10 min (±5 min around the time point) and CV threshold of 25% were used. While there is no established method for assessing RR recordings, the use of CV in assessing measurement error is well established.[19] With these collected data points, scatter plots with linear regression analyses and Bland–Altman analyses were performed between (1) manual documentation and telemetry, (2) manual documentation and capnography, and (3) telemetry and capnography. Lastly, we converted RR into dichotomous outcomes (RR ≤ 24 vs >24 breaths/min) and created a 2 × 2 table of detection of clinically significant tachypnea by each method. First, a single automated RR value was calculated by averaging the RR from telemetry and capnography. This value was kept only if the relative error between the two was ≤20% in order to select the time points that had good agreement between the automated methods. Using the 2 × 2 table, the rate of contradicting report of tachypnea was calculated for manual documentation and automated methods. All data analyses were performed using MATLAB.

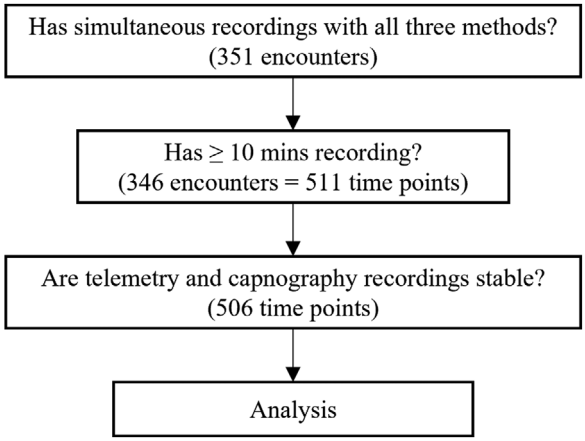

FIGURE 1 Selection of study subjects and time points.

3 | RESULTS

3.1 | Characteristics of study subject

A total of 351 ED encounters met the inclusion criteria, of which five encounters were excluded for insufficient quantity of telemetry or capnography data, leaving a total of 346 encounters. These encounters consisted of a total of 511 time points, and 506 time points met the stability criteria of CV ≤25%. The data selection process is shown in Figure 1. The demographics and clinical characteristics of the selected encounters are summarized in Table 1. The most common chief complaints of encounters included in this study were trauma (22%), psychiatric/ingestion (21%), dyspnea (8%), and weakness (7%). This is largely attributed to the inclusion criteria requiring the use of capnography. The significant presence of trauma patients is likely explained by the necessity of close respiratory monitoring with opioid pain medications.

3.2 | Main results

Manual documentation had a mean of 18.3 ± 3.9 breaths/min (±standard deviation). Telemetry had a mean of 19.1 ± 4.6 breaths/min, and capnography had a mean of 18.9 ± 5.6 breaths/min. The scatter plots with linear regression are shown in Figure 2, with manual documentation versus telemetry in Figure 2A, manual documentation versus capnography in Figure 2B, and telemetry versus capnography in Figure 2C. The linear regression analyses showed an *R*-value of 0.06 (95% confidence interval [CI] 0.00–0.12) for manual documentation versus telemetry, 0.07 (95% CI 0.01–0.13) for manual documentation versus capnography, and 0.82 (95% CI 0.79–0.85) for telemetry versus capnography.

The Bland–Altman plots are shown in Figure 3, with manual documentation versus telemetry in Figure 3A, manual documentation versus capnography in Figure 3B, and telemetry versus capnography in Figure 3C. Analyses showed a bias of −0.8 breaths/min (95% limits of agreement [LOA] −12.2 to 10.6 breaths/min) for manual

TABLE 1 Demographic and clinical characteristics.

Variables	$n = 346$ (100 %)
Age, years	**66 (48.3, 80)**
Sex	
Female	174 (50.3%)
Male	172 (49.7%)
Race/ethnicity	
Asian	12 (3%)
Black/African American	76 (22%)
Hispanic/Latinx	18 (5%)
Native American	3 (1%)
White	213 (62%)
Unknown/other	24 (7%)
CC (categories)	
Abdominal pain	16 (5%)
Allergic reaction	6 (1%)
Altered mental status	11 (4%)
Arrhythmia/palpitation	17 (4%)
Chest pain	14 (4%)
Dizziness	12 (4%)
Dyspnea	28 (8%)
Fever/ILI	12 (4%)
ICH/CVA	11 (3%)
Nausea/vomiting	3 (1%)
Pain	12 (3%)
Psychiatric/ingestion	72 (21%)
Seizure	7 (2%)
Syncope	4 (1%)
Trauma	75 (22%)
Urinary symptoms	6 (1%)
Weakness	21 (7%)
Wound/infection	5 (1%)
Other	14 (4%)
Respiratory support	
Room air	231 (67%)
Nasal canula	77 (22%)
Non-rebreather	13 4(%)
NIPPV	10 (3%)
HFNC	3 (1%)
Intubated	12 (3%)
ED length of stay, min	1103 (534, 1784)
Disposition	
Admitted	197 (57%)
Discharged	121 (35%)
Transferred	23 (7%)
Eloped/AMA	5 (1%)

Note: Age and ED (emergency department) length of stay are shown as median (IQR).

Abbreviations: AMA, against medical advice; CVA, cerebrovascular accident; ED, emergency department; HFNC, high-flow nasal cannula; ICH, intracranial hemorrhage; ILI, influenza-like illness; NIPPV, noninvasive positive pressure ventilation.

documentation versus telemetry, −0.6 breaths/min (95% LOA −13.5 to 12.3 breaths/min) for manual documentation versus capnography, and 0.2 breaths/min (95% LOA −6.2 to 6.6 breaths/min) for telemetry versus capnography.

Table 2 shows the 2 × 2 table of detection of clinically significant tachypnea. These data are also visualized in Figure 4, which shows the scatter plot between manual documentation and automated methods with depiction of contradicting reports between the two methods. The red markers indicate the time points when clinically significant tachypnea was reported by automated methods but not by manual documentation, which occurred 94% of the time. Conversely, the blue markers indicate the time points when clinically significant tachypnea was reported by manual documentation but not by automated methods, which occurred 87% of the time.

4 | LIMITATIONS

This study has several limitations. First, this was a single-center study and therefore generalizability of the findings from this study may be limited. Second, the study population had to have been on capnography, which is not representative of the general ED patient population and results in selection bias. However, this bias is toward selecting patients who are likely unstable and have increased likelihood of decompensating. Although this reduces generalizability of this work to the overall ED patient population, the study result is more pertinent to the patient population who require closer RR monitoring. Third, due to the lack of additional documentation, it was not possible to ascertain the reason for manual documentation at a specific time point as well as the source of the documented values. Fourth, there was no ground truth measurement performed in this study. While capnography is typically regarded as the most accurate method for RR monitoring, capnography data still had a significant amount of variability and noise such that it was difficult to consider it as the ground truth.

5 | DISCUSSION

This retrospective observational study reviewed a large number of real patient encounters to evaluate the reliability of RR monitoring in a busy ED. To our knowledge, this is the first study that has looked at real-world practice of RR monitoring throughout the ED stay.

The scatter plots and linear regression analyses showed poor correlation between manual documentation and the automated methods. This lack of correlation was apparent even on visual inspection of the scatter plots, which showed essentially no relationship between manual documentation and other methods. In contrast, there was a clear linear relationship between telemetry and capnography despite some outliers. Bland–Altman analyses showed small biases of <1 breaths/min for all method pairs. However, LOA exceeded ±10 breaths/min between manual documentation and both automated methods, which is unacceptably large given that typical RRs are in the 10s to 20s breaths/min. In contrast, the automated

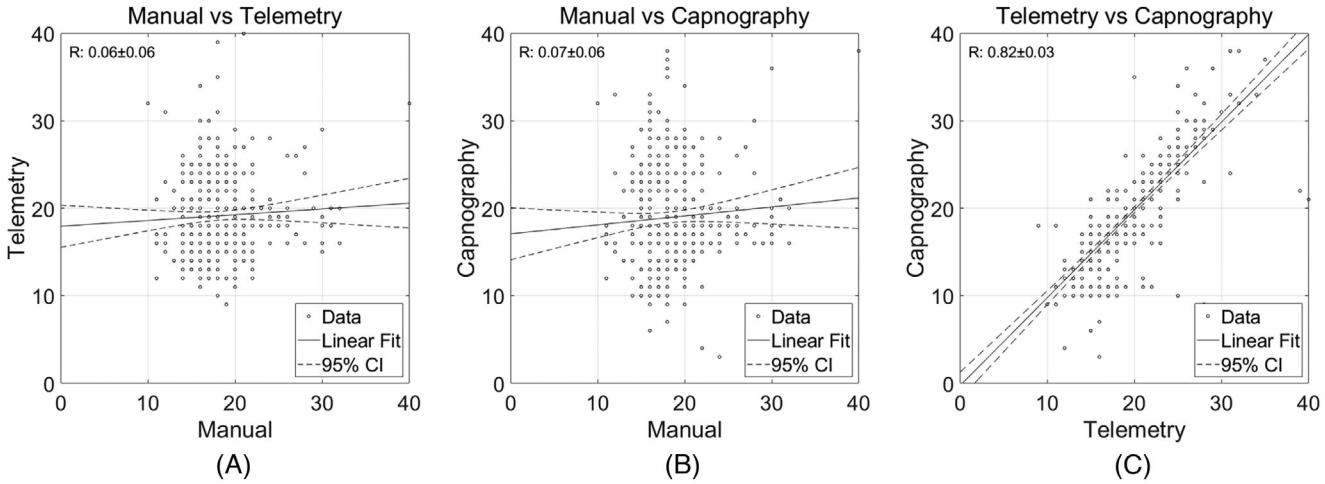

FIGURE 2 Scatter plots and linear regression analyses between (A) manual documentation and telemetry, (B) manual documentation and capnography, and (C) telemetry and capnography. The linear fit is shown as a solid line, and the upper and lower limits of the 95% confidence interval are shown as dotted lines.

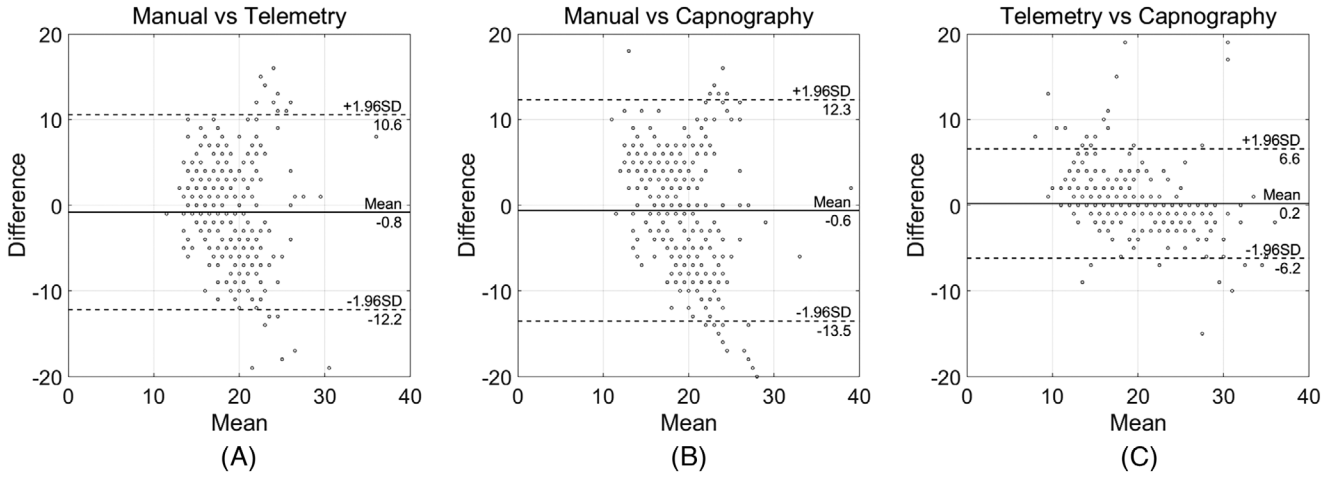

FIGURE 3 Bland–Altman plots between (A) manual documentation and telemetry, (B) manual documentation and capnography, and (C) telemetry and capnography. The bias is shown as a solid line and the 95% limits of agreement are shown in dotted lines.

TABLE 2 A 2 × 2 table showing frequency of identifying tachypnea by each method.

		Manual		
		>24	**≤24**	**Total**
Automated	>24	4	62	66
	≤24	27	354	381
	Total	31	416	

Note: Clinically significant tachypnea is defined as respiratory rate > 24 breaths/min.

methods showed a better agreement with smaller LOA of around ±6 breaths/min. However, given that the generally accepted accuracy requirement for RR monitors is ±2 breaths/min,[20,21] this is still too large from a clinical acceptability perspective. Lastly, assessing the discrepancy in detecting clinically significant tachypnea showed that detection by manual documentation was inconsistent with automated methods 80–90% of the time, which could potentially lead to missing unstable or decompensating patients or initiating unnecessary interventions.

In interpreting the results of these analyses, it is important to remember that no ground truth measurements were performed in this study, and therefore it was not possible to assess the absolute accuracy of each method. However, given the agreement observed between automated methods that employ distinct technologies with different sources of error, it is reasonable, although speculative, to conclude that the RR reported by the automated methods is likely closer to the true RR.

Also, due to the lack of explicit documentation, it is not possible to determine the reason and source of each of the manually documented data points. However, based on the results of the analyses, two important conclusions are deducible. First, given the poor correlation

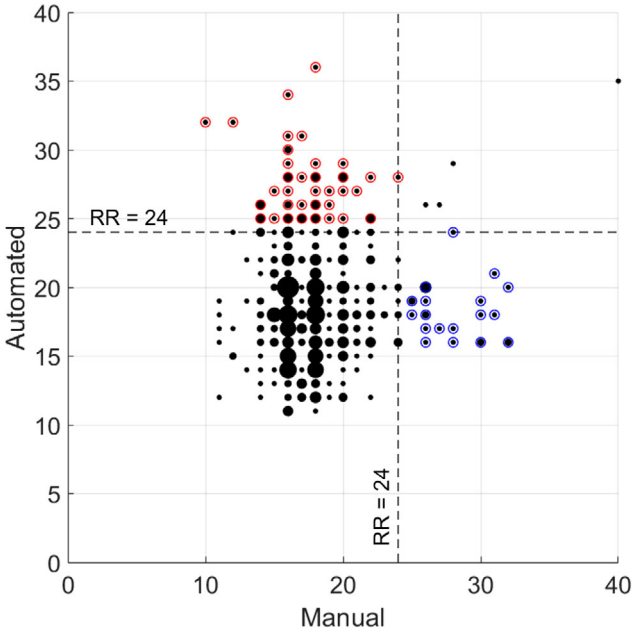

FIGURE 4 Scatter plot between manual documentation and automated methods. The red markers indicate the time points when clinically significant tachypnea was reported by automated methods but not by manual documentation. The blue markers indicate the time points when clinically significant tachypnea was reported by manual documentation but not by automated methods. The size of the scatter indicates the frequency of the occurrence.

between manual documentation and the automated methods, it was unlikely that the manually documented values mostly came from the monitor. Second, assuming that the value had come from actually counting the RR, the poor correlation with the automated methods would imply that the ED staff were highly inaccurate in performing manual counting. While this is still a possibility, it is still difficult to explain the extent of the discrepancy. Rather, a more likely explanation is that the manually documented values were "estimations" based on the patient's appearance, especially given the high frequency of 16 and 18 breaths/min seen in the manually documented RRs as noted in previous works.[15]

The challenges associated with RR monitoring are well known. Several studies have shown that RR monitoring is highly unreliable even in controlled settings. In one study with 140 ED patients, two trained observers who manually assessed RR were found to have LOA of ±6.2 breaths/min and interobserver variability as high as 35%.[18] In another study, 448 healthcare professionals assessed RR while watching videos of volunteers breathing at a fixed rate. The study showed that there was only moderate agreement between the raters and the incorrect measurements influenced several important clinical rules (i.e., Systemic Inflammatory Response Syndrome and National Early Warning Score).[3] Similar findings were seen in ED triage settings. In a study by Lovett et al.,[12] RR documented by triage nursing was compared to ground truth measurement performed by research assistants, which showed significant discrepancy with LOA of −8.6–9.5 breaths/min. In a similar study by Bianchi et al.,[15] RR documented by triage nursing and ground truth measurement had similar LOA around −9 to 9 breaths/min and clustering around 16 and 18 breaths/min. By assessing the reliability of RR monitoring throughout the ED stay, this study not only re-demonstrates the challenges in RR monitoring in clinical settings, but also raises concern that manually documented RR during the ED stay may be even more affected by these challenges. This can be inferred from the LOA of >± 10 breaths/min between manual documentation and automated methods seen in this study, which is even larger than what was seen in other studies performed in ED triage settings.

It is worth recognizing that this challenge is largely unique to RR monitoring and not to other vital signs. The underlying reason is multifactorial.[22] Although we are not able to ascertain these reasons in this study, findings here in addition to prior studies suggest some of it is likely driven by limitations in technology that lead to mistrusting of the automated measurements and result in estimating the RR.[14,23,24] Ultimately, a more reliable RR monitoring technology is needed to solve this problem. This is an active research area with devices based on various modalities such as acoustic, thermal, optical, and radar.[25–27] However, in the mean time, it is essential to (1) recognize that manually documented RR in patient charts during the ED stay used to inform patient care decisions is highly unreliable and (2) develop system- and policy-driven approaches to enhance its reliability.

In conclusion, this is a retrospective study performed at a busy tertiary care ED to compare real-world RR monitoring via manual documentation, telemetry, and capnography. After evaluating 351 ED encounters spanning 2 years, the study demonstrated poor agreement between manual documentation and automated methods while significantly better agreement between the two automated methods. The findings of this study highlight the need for more accurate RR monitoring technologies as well as the need to further investigate the methodology used by the ED staff in monitoring RR to improve its reliability given that many important clinical decisions are made based on these assessments.

AUTHOR CONTRIBUTIONS

John H. Lee, Brian W. Anthony, Nathan I. Shapiro, and Alon S. Dagan conceived and designed the study. Larry A. Nathanson performed data collection. John H. Lee, Ryan C. Burke, Brian W. Anthony, Nathan I. Shapiro, and Alon S. Dagan analyzed the data. John H. Lee drafted the manuscript, and all authors contributed substantially to its revision. John H. Lee takes responsibility for the paper as a whole.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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