Respiratory Rate Predicts Cardiopulmonary Arrest for Internal Medicine Inpatients

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Objective: To assess whether vital sign measurements could identify internal medicine patients at risk for cardiopulmonary arrest.
Design: Retrospective case-control study comparing 72 hours of pre-arrest vital sign measurements with 72 hours of vital sign measurements for patients from the same units who did not experience cardiopulmonary arrest.
Setting: Twelve non-intensive care internal medicine units at a large midwestern academic medical center.
Patients: Cases included all 59 inpatients who had experienced cardiopulmonary arrest between May 1989 and December 1990; patients who were designated do-not-resuscitate (DNR) or had less than 72 hours of vital sign recordings were excluded. Controls included 91 inpatients without cardiopulmonary arrest who were matched for units and who had 72 hours of vital sign recordings.
Results: The occurrence of one or more respiratory rates > 27 breaths per minute over a 72-hour period had a sensitivity of 0.54 and a specificity of 0.83 (odds ratio = 5.56, 95% CL = 2.67–11.49) in predicting cardiopulmonary arrest. Other respiratory rate thresholds were also predictive of arrest. The ability of respiratory rate to predict arrest was stronger in units with high incidences of arrest relative to units with low incidences, for example, in units for the management of gastrointestinal disease (sensitivity = 1.00, specificity = 0.86) and renal disease (sensitivity = 0.69, specificity = 0.87). Respiratory rate remained a significant predictor ($p < 0.001$) after controlling for patient age and gender. Pulse rate and blood pressure were not predictive of cardiopulmonary arrest.
Conclusions: Using elevated respiratory rates as a signal for focused diagnostic studies and therapeutic interventions in internal medicine patients may be useful in reducing the incidence of subsequent cardiopulmonary arrest, and lowering associated morbidity and mortality.
Key words: cardiopulmonary arrest; respiratory rate; internal medicine; prediction; vital sign measurement.
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THE SERIAL MEASUREMENT of vital signs to monitor patients for change in medical status is a time-honored tradition.[1] Several studies have suggested that serial respiratory rate measurements are of value for predicting deterioration in various clinical settings.[2-4] An increasing respiratory rate also predicts respiratory failure secondary to muscle weakness and fatigue in patients being weaned from the ventilator[5-7] and patients at risk for acute respiratory distress syndrome,[8] and predicts respiratory dysfunction in patients with cystic fibrosis.[9] Monitoring respiratory rate has also been a reliable indicator of respiratory dysfunction in surgical patients during the first three postoperative days[10] and in elderly patients suffering from lower respiratory tract infections.[11]

There is little information in the literature about the usefulness of measuring respiratory rate as a predictor of cardiopulmonary arrest for patients on internal medicine units.[1-5] One study[4] noted elevated respiratory rate among general medicine patients in the hours preceding arrest, but this study did not include a control group and left unanswered the question of whether respiratory rate was a useful predictor of arrest. Another study[2] found an elevated rate of >20 breaths per minute in 55% of cardiac arrest patients prior to arrest, but this study also lacked a control group. These studies report no consistent thresholds beyond which an elevated respiratory rate signals deterioration.

Schein et al.[3] noted that 34 of 64 patients deteriorating to cardiopulmonary arrest had respiratory complaints and 18 had abnormal respirations. Since most of these patients had underlying disease not judged to be rapidly fatal, the authors suggest that efforts to predict and prevent arrests might be useful.

Pulse rates and blood pressure are also routinely measured vital signs. A small number of studies have evaluated the efficacy of using these pre-arrest variables to predict survival following cardiopulmonary resuscitation (CPR).[2, 12, 13] In these studies, hypotension defined as a systolic blood pressure < 100 mm Hg occurred in 26–37% of the patients. Tachycardia (heart rate > 110 beats per minute) was noted in 26–36% of the cases. Unfortunately, these variables were recorded only during brief pre-arrest periods: one day,[12] four hours,[2] or at onset of arrest.[13] For each of these studies the outcome measure of interest was post-arrest survival. Because of the short pre-arrest time frame and the goals of the studies, no attempt was made to use these abnormal vital signs to predict cardiopulmonary arrest. Pulse and blood pressure are included in the computation of illness severity in the APACHE II system for intensive care unit patients,[14] but their individual predictive contributions are not detailed.

The extent to which blood pressure, pulse, and respiratory rate predict cardiopulmonary arrest among internal medicine inpatients is thus unknown. Ideally, one would want to identify high-risk patients for CPR at a time sufficiently early to intervene and reduce the risk. No previous study has examined vital sign readings for periods longer than a few hours prior to arrest.

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Therefore, the present study was designed to assess the utility of various respiratory rate, pulse rate, and blood pressure values in a three-day pre-arrest period as monitors to identify those patients on internal medicine units at risk for cardiopulmonary arrest.

METHODS

Study Design and Subjects

A retrospective case – control study was conducted based on an initial sample of 74 internal medicine unit patients who had experienced cardiopulmonary arrest necessitating a CPR attempt during the study period May 1989 through December 1990. Fifteen patients with less than 72 contiguous hours of vital sign monitoring prior to CPR were excluded, resulting in a final sample of 59 cases; the 15 excluded patients were retained for separate analysis. The time frame requirement was selected to ensure a reasonable length of time for monitoring and intervention by the attending medical team. Patients were housed on 12 non – intensive care internal medicine units at a large midwestern academic medical center. In the 72 hours prior to arrest, an average of 10.0 blood pressure, 9.9 pulse rate, and 9.8 respiratory rate measurements were recorded per patient in the medical records.

At this hospital, there are 12 beds in the medical intensive care unit available for monitoring and treatment of acutely ill patients who meet admission criteria. In addition, there are 12 beds in the cardiovascular intensive care unit and 26 beds in the surgical intensive care unit for overflow patients; no patient has been denied access to intensive care on the basis of unavailability. The 59 cases, then, are all patients who were not considered to be in need of transfer from the internal medicine units to intensive care.

Because only a small number of patients on the internal medicine service deteriorate to cardiopulmonary arrest (three per month on average), it is difficult to develop a control group from the large numbers of patients who do not have cardiopulmonary arrests. Our control group was selected from patients hospitalized on the same inpatient units as the CPR group over the contiguous period January 3 to 5, 1991. The total censuses on the 12 units for the three days of evaluation were 149, 145, and 136 patients, respectively; however, only 92 patients remained over the entire three-day interval. Of these, one patient who required CPR was excluded from the analysis. Thus, 91 patients were serially monitored for blood pressure, pulse, and respiratory rate over the three-day study period. The mean numbers of blood pressure, pulse rate, and respiratory rate determinations over the 72-hour period for the control group were the same as for the cardiopulmonary arrest group.

Controls were matched with CPR cases based on unit location and duration of observation, but not for other variables such as age, gender, or diagnosis. We believe these matching criteria promote an externally valid comparison in that we are concerned with prediction of arrest among the internal medicine unit population, and not among selected groups within the population. We also examined the statistical effects of age and gender on prediction of arrest.

Vital Sign Determination

Staff nurses were responsible for routine measurement and recording of vital signs at least every eight hours or once every shift. The recorded values were not validated by mechanical recorders. Clinically determined values outside the range set by the unit team (respiratory rate > 30 or < 8 breaths per minute, systolic blood pressure > 180 or < 100 mm Hg, and pulse rate > 120 or < 50 beats per minute) were routinely rechecked by the nursing supervisor of each floor. If measurements were confirmed to be abnormal, the housestaff team was called to validate the measurement and evaluate the patient. Hence, abnormal values were checked by multiple observers. The differences in the mean numbers of recordings for each vital sign reflect follow-up measurements of abnormal vital signs at more frequent intervals.

Data Collection and Analyses

Data were transcribed from medical records onto data collection forms by one of the authors (JFF) and the director of nursing quality assurance. Data collected included recorded vital signs, age and gender, discharge diagnoses, inpatient unit, CPR outcome, and discharge disposition.

The incidence of CPR by unit was determined by dividing the number of CPR occurrences by the number of unit patients during the 20-month study period.

Thresholds demarcating abnormal readings for each type of vital sign were examined at regular intervals: respiratory rate at every 2-point interval from > 21 to > 31 breaths per minute; pulse rate at 10-point intervals from > 100 to > 130 beats per minute; and systolic blood pressure at 10-point intervals from > 139 to > 179 mm Hg and 10-point intervals from > 110 to < 90 mm Hg. Exploratory analyses using combinations of vital sign thresholds were also undertaken.

The usefulness of thresholds was examined by calculating odds ratios, sensitivities, and specificities, and by performing maximum likelihood logistic regression analyses.[15] We did not compute predictive value because of the low incidence of cardiopulmonary arrest in the population as a whole. Sensitivity is the proportion of arrests predicted to be arrests. Specificity is the proportion of non-arrests predicted to be non-arrests. Logistic regression was used to determine the significance of a vital sign cutoff score as a predictor of arrest while controlling for patient age and gender. Sensitivity and

TABLE 1

Numbers and Percentages of Subjects by Unit in Arrest and Control Groups, and Incidence of Cardiopulmonary Resuscitation (CPR) by Inpatient Unit from May 1989 to December 1990

	Arrest Group		Control Group		CPR Cases per Thousand
Unit	Number	%	Number	%	Admissions
Bone marrow	3	5.1	11	12.1	17.9
Cardiology	18	30.5	11	12.1	6.6
Diabetes	1	1.7	2	2.2	1.0
Gastrointestinal	7	11.9	7	7.7	4.3
General medicine	5	8.5	12	13.2	2.1
General medicine/cardiology	2	3.4	7	7.7	3.4
Medical psychiatry	2	3.4	8	8.8	3.3
Oncology/hematology	1	1.7	4	4.4	1.5
Oncology/solid tumor	2	3.4	2	2.2	2.6
Pulmonary	5	8.5	12	13.2	4.3
Renal/general medicine	13	22.0	15	16.5	6.2
TOTAL	59	100.0*	91	100.0*	4.3

*Columns sum to 100% within rounding error.

specificity analyses of unit and age-specific subsamples were also undertaken.

RESULTS

Between May 1989 and December 1990, 74 internal medicine unit patients experienced cardiopulmonary arrest necessitating CPR. Fifteen patients were excluded from the CPR case sample because their arrests occurred within 72 hours of admission.

Demographics

The mean age of cases (61.9 years; SD = 16.2, range = 18 to 88) was significantly higher than that of controls (53.9 years; SD = 17.3, range = 17 to 92) ($t = 2.85$, $p < 0.01$). Of the cases, 50.8% were women, relative to 46.2% of the controls, a nonsignificant difference. Forty-two (71.2%) of the cases survived past the immediate CPR, and 13 (22.0%) survived to discharge. Although our survival rates are somewhat higher than published rates, they are consistent with the yearly rates accumulated for the hospital by the CPR committee. The numbers of cases and controls in each unit are shown in Table 1.

Of the 15 CPR patients excluded from the study, the mean age (61 years), gender ratio (46.7% female), and survival rates (immediate 66.7%, to discharge 33.3%) were not statistically different from those of the patients who had experienced CPR after the 72-hour monitoring period.

TABLE 2

Sensitivity, Specificity, Odds Ratio (OR), and 95% Confidence Limits (CL) for Selected Vital Sign Thresholds

	Group %					
Vital Sign	Arrest ($n = 59$)	Control ($n = 91$)	Sensitivity	Specificity	OR	95% CL
Respiratory rate (breaths per minute)						
>21	0.86	0.66	0.86	0.34	3.29	1.39–7.81
>23	0.83	0.54	0.83	0.46	4.20	1.94–9.22
>25	0.58	0.24	0.58	0.76	4.27	2.11–8.61
>27	0.54	0.17	0.54	0.83	5.56	2.67–11.49
>29	0.44	0.11	0.44	0.89	6.38	2.77–14.64
>31	0.42	0.08	0.42	0.92	8.82	3.53–22.24
Pulse rate (beats per minute)						
>100	0.51	0.44	0.51	0.56	1.32	0.69–2.55
>110	0.41	0.25	0.41	0.75	2.83	1.35–5.90
>120	0.22	0.11	0.22	0.89	2.29	0.93–5.64
>130	0.12	0.09	0.12	0.91	1.40	0.48–40.8
Systolic blood pressure (mm Hg)						
>139	0.53	0.43	0.53	0.57	1.48	0.75–2.92
>149	0.42	0.31	0.42	0.69	2.34	1.13–4.86
>159	0.40	0.23	0.40	0.77	1.35	0.65–2.80
>169	0.24	0.16	0.24	0.84	1.58	0.70–3.56
>179	0.12	0.09	0.12	0.91	1.40	0.48–4.08

Table 1 also provides data for the incidence of cardiopulmonary arrest by inpatient unit. Specialty units with the highest rates of cardiopulmonary arrest were bone marrow transplantation (17.9 per 1,000), cardiology (6.6 per 1,000), renal (6.2 per 1,000), gastrointestinal (GI) (4.3 per 1,000), and pulmonary (4.3 per 1,000).

Sensitivity and Specificity

As shown in Table 2, respiratory rate was a significant predictor of cardiopulmonary arrest across a wide range of thresholds according to the odds ratio (OR) analyses, considering that the 95% confidence limits (CL) exclude 1. This table also shows that as respiratory rate increased, specificity increased and sensitivity declined. That is, at the lower boundary of the studied range, an abnormal rate occurred in most cases (e.g., 83% of those with a reading >23 breaths per minute.) These lower rates also captured a larger percentage of the controls, however. At higher rates, very few controls were captured (e.g., only 7% at > 31 breaths per minute), but at the expense of a lower sensitivity.

Pulse and blood pressure were not generally predictive of arrest. For pulse rates, the only cutoff score with a significant odds ratio was a reading of >110 beats per minute (OR = 2.83, 95% CL = 1.35–5.90). This cutoff score had a sensitivity of 0.41 and a specificity of 0.75. The only systolic blood pressure cutoff score with a significant odds ratio was a reading > 149 mm Hg (OR = 2.34, 95% CL = 1.13–4.86). The sensitivity of this cutoff score was 0.42 and the specificity was 0.69. Exploratory combinations of respiratory rate with other vital signs were also not useful, because these combinations occurred so rarely as to produce low sensitivities.

Subgroup Analyses

We selected a respiratory rate of > 27 breaths per minute for further analysis using subgroups of patients after analyzing various cutoffs. We chose > 27 because it reduced false positives relative to rates > 25 with only a slight drop in sensitivity. This threshold provided a clinically useful tool with limited false-positive cases.

First, we determined that age was not associated with the occurrence of this elevated respiratory rate (t = 0.3, df = 148, NS), reducing the possibility that the association between respiratory rate and cardiopulmonary arrest was confounded by age. Next, we determined whether this cutoff score was a significant predictor of cardiopulmonary arrest after controlling for patient age and gender. A logistic regression analysis where all three predictors were entered simultaneously indicated that both age and the respiratory rate cutoff were significant independent predictors, but that gender was not (Table 3).

TABLE 3

Logistic Regression Results, Total Sample (*N* = 150)—Prediction of Cardiopulmonary Resuscitation (CPR) from Age, Gender, and a Respiratory Rate > 27 Breaths per Minute

	Parameter Estimate	Standard Error	p Level
Age	0.04	0.02	<0.01
Gender	−0.16	0.38	NS*
Respiratory rate	1.88	0.41	<0.001

*NS = not significant.

As patient age was significantly associated with risk for cardiopulmonary arrest, we grouped age into a number of discrete categories to determine whether certain age categories were more likely to demonstrate an association between the respiratory rate cutoff and the need for CPR. The categories and odds ratio results were: less than 30 years old (OR = 15.0, 95% CL = 0.57–400.93); aged 30 to 49 (OR = 4.8, 95% CL = 0.89–26.10); aged 50 to 64 (OR = 7.5, 95% CL = 1.97–28.28); and older than 64 (OR = 4.46, 95% CL = 1.31–15.06). Thus, the odds ratios were significant only for the two older age categories, which included patients over 50.

Next, we chose the units with cardiopulmonary arrest rates equal to or higher than the average rate (bone marrow, cardiology, GI, pulmonary, and renal) for further analysis. Results of these analyses are provided in Table 4). The respiratory rate cutoff of > 27 breaths per minute was a good predictor in all of these high-risk units except cardiology. For example, of the seven CPR cases from the GI unit, all had one or more readings > 27 breaths per minute, compared with only one of seven GI unit controls, for a sensitivity of 1.00 and a specificity of 0.86. The same reading was present for nine of 13 CPR cases from the renal unit, and for only two of 15 controls, for a sensitivity of 0.69 and a specificity of 0.87. Thus, consideration of high-risk units increase the predictive ability of respiratory rate.

We also examined the sensitivity and specificity of a respiratory rate of > 27 breaths per minute among patients older than 50, overall and in the high-risk units (Table 4). Overall, 47 of the 59 cases were at least 50 years old, and 25 were correctly predicted to be at risk on the basis of a respiratory rate > 27 breaths per minute (sensitivity = 0.53). Fifty-three of the controls were at least 50, and 44 were correctly predicted (specificity = 0.83). Generally, sensitivity and specificity were not appreciably improved by focusing on patients older than 50.

Separate analyses for the 15 patients excluded from the study by virtue of the short monitoring period (average 24.8 hours, range 1 to 45 hours post admission) revealed that a respiratory rate > 27 breaths per minute had occurred in only 33% of the patients. Thus, monitoring respiratory rates may not be as useful for

TABLE 4

Results of Sensitivity and Specificity Analyses, for a Respiratory Rate Cutoff of > 27 Breaths per Minute, for Units Combined and for High-risk Units

	All Patients			Patients > 50 Years Old		
Unit	*n*	Sensitivity	Specificity	*n*	Sensitivity	Specificity
All	150	0.54	0.82	100	0.53	0.83
Bone marrow	14	0.67	0.82	2	NA*	0.50
Cardiology	29	0.11	0.73	22	0.13	0.86
Gastrointestinal	14	1.00	0.86	5	1.00	1.00
Pulmonary	17	0.60	0.58	12	0.60	0.71
Renal	28	0.69	0.87	21	0.75	0.78
All high-risk	102	0.50	0.77	62	0.49	0.78
All high-risk minus cardiology	73	0.75	0.78	40	0.75	0.75

*NA = not applicable.

identifying patients who will have cardiopulmonary arrests early during their inpatient stays.

Timing of Respiratory Elevation

Among the 32 cases who had at least one respiratory rate recording of > 27 breaths per minute, we examined the day on which the elevated rate had first occurred. It occurred on the first day of recording for 20 of these cases, the second day for eight of the cases, and the third day (closest to the actual CPR) for four of the cases. For only 2 of the 32 cases was the first elevated reading the very last reading before CPR. Further, of the 20 cases for whom an elevated reading occurred on the first day, in only two did it occur on only that day. Among patients with at least one elevated reading, the average number of elevated readings per patient was 4.5 (SD = 3.5, range = 1 to 15). It is clear that there is usually an extended period between the first of repeated elevated rates and the need for CPR, indicating that time to make potentially corrective measures is often available.

Among the five units with the highest rates of cardiopulmonary arrest, there were 23 who had at least one elevated respiratory rate. Fourteen of the elevated rates occurred first on the first day of recording, five on the second day, and only four on the third day.

DISCUSSION

Our study suggests that close observation of respiratory rate identifies many of the patients at risk for cardiopulmonary arrest. Fifty-four percent of the patients requiring CPR had at least one recorded respiratory rate > 27 breaths per minute during the 72 hours prior to arrest. This is consistent with previously reported uncontrolled data where new-onset dyspnea with tachypnea preceded arrest in 33–55% of patients.[2, 3] The present results for pulse and blood pressure are also consistent with earlier uncontrolled data indicating systolic blood pressure < 90 mm Hg in 27% of pre-arrest patients, and heart > 100 beats per minute in 36% of pre-arrest patients, compared with the 55% who had tachypnea.[2]

It is not entirely clear why patients with abnormal respiratory rates are at risk for cardiopulmonary arrest. As noted by Knaus et al.,[16] there appears to be a uniformity of response to abnormal physiology caused by disease processes. Therefore, it should not be surprising that certain disease states, such as hypoxemia, acidosis, sepsis, increased intracranial pressure, and hypotension, are capable of inducing tachypnea. These disease states all have the potential to lead to arrest. By immediate intervention directed toward the underlying condition, the arrest might be avoided, thus reducing mortality, morbidity, and cost.

Although it is important to identify those patients at risk, it is also important for a monitor to minimize false positives. A full work-up on every patient who surpasses a cutoff score of high sensitivity but lower specificity might lead to an increase in hospital costs and services while placing an undue burden on busy medical staff. By using a cutoff score of > 27 breaths per minute 16 (17.4%) control patients would have been identified for special attention over a three-day period. If these numbers held true throughout the month, 160 evaluations would be necessary to identify and possibly change the course of approximately three patients who ultimately experience cardiopulmonary arrest and undergo CPR. In addition, this strategy may identify other patients in the process of deterioration who might not experience arrest but might still benefit from emergency respiratory support. These additional evaluations are not so overwhelming when divided among the 42 housestaff and 14 attending physicians assigned to these units.

Location on a high-risk unit and an elevated respiratory rate offered greater prediction than did the elevated rate by itself. This unit-specific prediction was most apparent for patients admitted to the renal and GI units. Increased respiratory rate on these units may reflect acidosis, hypovolemia, or sepsis. It is interesting to speculate why an increasing respiratory rate did not precede cardiopulmonary arrests on the cardiology unit. Most arrests on this ward were sudden, unpredictable events precipitated by malignant arrhythmias, noted by electrocardiographic telemetry monitoring. The rapid sequencing of the events from a normal heart rhythm to a malignant arrhythmia with cardiopulmonary arrest precluded complaints of tachypnea or a record revealing a progressive increase in respiratory rate.

Although age was significantly associated with risk for cardiopulmonary arrest, it did not provide much, if any, additional sensitivity or specificity over respiratory rate used alone. Therefore, patients in internal medicine units may be monitored for the occurrence of this marker regardless of age.

The results indicate that there is often time, up to two days or more, between the first occurrence of an elevated respiratory rate and the need for CPR, during which evaluation and intervention may be taken. A simple strategy would involve physician evaluation of all patients with respiratory rates > 27 breaths per minute or some other locally determined threshold. An increased rate that cannot be readily explained might precipitate further selected laboratory screening such as chest x-ray, electrocardiography, arterial blood gas analysis, and repeat blood work. Intensive care monitoring may be appropriate based on the patient's course and laboratory findings. In review, this potential protocol uses a two-step level of intervention: The first step identifies those patients at risk for deterioration and institutes an observational and evaluative strategy. The second step sets the level of care based on the patient course and results of the initial studies.

There are certain limitations of a clinical study such as this. For example, respiratory rate counting by nursing personnel may not always be accurate and reproducible.[1,17] Errors are often compounded by the traditional method of counting respiratory rate for 15 seconds and multiplying by four. Despite the hope that technology would solve some of the accuracy problems associated with respiratory rate counting, no device to date has been more accurate than counting.[18,19] Second, our study was an exploratory retrospective review. The three-day recording period of the control group may not be representative of the internal medicine population as a whole, and the benefits of respiratory rate monitoring may not apply as strongly to patients who deteriorate earlier. A prospective study to confirm the particular cutoff scores found to be optimal here is needed to validate our findings and to determine whether early detection of compromise will lead to better outcomes. A prospective study may also investigate specific disease states that may be associated highly with increased respiratory rate and arrest. In addition, future studies may use a severity of illness matching process to produce more equivalent comparison groups.

If future research supports the use of specified respiratory rates to trigger responses to prevent cardiopulmonary arrest, a new hospital- or unit-level measure of quality may emerge: respiratory-rate-adjusted cardiopulmonary arrest incidence. This measure may be taken as an index of avoidable adverse outcomes. Bedell et al.[20] noted that 18% of preventable iatrogenic cardiac arrests were caused by failure to respond to abnormal signs and symptoms related to the respiratory system. In the intensive care unit setting, a sudden change in respiratory rate is met with an immediate response. It is interesting to speculate why a similar finding produces so little activity on the general medicine units.

Despite concerns about unreliability of the test, the simple counting of a respiratory rate proved a powerful predictor of respiratory dysfunction. With simple monitoring techniques these patients can be identified early. Close monitoring and immediate intervention may improve their ultimate prognoses. If this can be documented in further studies, physicians will be better able to select which patients require close monitoring. Although the monitoring costs may rise, the ultimate costs in human life and prolonged intensive care unit utilization may be decreased significantly.

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