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Oxygen Flow Rate Requirements of Critically Injured Patients

Jason McMullan, MD; Kimberly Ward Hart, MA; Chris Barczak, BS, MT(ASCP); Christopher J. Lindsell, PhD; Richard Branson, MSc

University of Cincinnati

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Air Force Research Laboratory
711th Human Performance Wing
U.S. Air Force School of Aerospace Medicine
Aeromedical Research Department
2510 Fifth St.
Wright-Patterson AFB, OH 45433-7913

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Jason McMullan, MD
Kimberly Ward Hart, MA
Chris Barczak, BS, MT(ASCP)
Christopher J Lindsell, PhD
Richard Branson, MSc

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14. ABSTRACT
The optimal amount of oxygen to deploy with pararescue personnel for combat casualty care is currently unknown. Our objectives are to determine the proportion of trauma patients requiring supplemental oxygen and the minimal flow rate required by those patients and to evaluate associations between patients' injury characteristics and oxygen requirements to identify those most at risk for requiring oxygen. Over 6 months, dedicated study assistants prospectively observed oxygen requirements and supplemental oxygen provision to trauma patients meeting our institution's highest-level trauma team activation criteria during the first 3 hours of emergency care. Results were calculated as proportions or risk ratios with 95% confidence intervals. The mean age of 204 enrolled subjects was 37 years, 161/204 were male, median injury severity score was 9 (interquartile range 1-21), and 119/204 suffered penetrating injuries. The majority of subjects were admitted (141/204, 69%), with most going directly to the operating room (35/141) or intensive care unit (78/141) from the emergency department. Penetrating injuries were less likely to require supplemental oxygen (respiratory rate 0.65, 95% confidence interval 0.50-0.84). Subjects with Glasgow Coma Scale scores <15, hypotension, abdominal injury (abdomen abbreviated injury score >1), and chest injury (chest abbreviated injury score >1) were likely to require supplemental oxygen. The majority of never-intubated adult trauma patients can be managed with no or low flow supplemental oxygen. There is significant opportunity to reduce the need for oxygen delivery to the battlespace.

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Supplemental oxygen, trauma, emergency care

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1.0 SUMMARY

The optimal amount of oxygen to deploy with pararescue personnel for combat casualty care is currently unknown. Our objectives are to determine the proportion of trauma patients requiring supplemental oxygen and the minimal flow rate required by those patients and to evaluate associations between patients' injury characteristics and oxygen requirements to identify those most at risk for requiring oxygen. Over 6 months, dedicated study assistants prospectively observed oxygen requirements and supplemental oxygen provision to trauma patients meeting our institution's highest-level trauma team activation criteria during the first 3 hours of emergency care. Results were calculated as proportions or risk ratios with 95% confidence intervals. The mean age of 204 enrolled subjects was 37 years, 161/204 were male, median injury severity score was 9 (interquartile range 1-21), and 119/204 suffered penetrating injuries. The majority of subjects were admitted (141/204, 69%), with most going directly to the operating room (35/141) or intensive care unit (78/141) from the emergency department. Penetrating injuries were less likely to require supplemental oxygen (respiratory rate 0.65, 95% confidence interval 0.50-0.84). Subjects with Glasgow Coma Scale scores <15, hypotension, abdominal injury (abdomen abbreviated injury score >1), and chest injury (chest abbreviated injury score >1) were likely to require supplemental oxygen. The majority of never-intubated adult trauma patients can be managed with no or low flow supplemental oxygen. There is significant opportunity to reduce the need for oxygen delivery to the battlespace.

2.0 BACKGROUND

Supplemental oxygen is required to correct hypoxemia and is often used to augment tissue oxygen delivery following hemorrhagic shock or in a prophylactic attempt to avoid secondary injury after traumatic brain injury [1,2]. However, supplemental oxygen is frequently overused in the prehospital setting, even in patients without severe traumatic injuries [3]. In many acute medical conditions, use of supplemental oxygen and hyperoxia have been associated with no benefit or worsened clinical outcomes [4-10].

Beyond the clinical implications of hyperoxia, provision of supplemental oxygen poses significant logistical challenges in austere and limited-resource situations and, in the tactical or military setting, could pose operational security concerns. Determining the minimal flow of oxygen required to treat critically injured patients is an essential step in deciding what medical equipment to deploy and is essential information for logistical and medical planners.

Our objective is to describe the flow of supplemental oxygen required to correct hypoxemia in severely injured trauma victims. Secondarily, we evaluate associations between patients' injury characteristics and oxygen requirements to identify those most at risk for requiring oxygen to provide pararescue personnel with guidance as to the minimum oxygen requirements for optimal combat casualty care.

3.0 METHODS

3.1 Study Design

We conducted a prospective, observational cohort study to track supplemental oxygen administration in trauma patients during the first 3 hours of care and to estimate the minimum level required to maintain satisfactory oxygen saturation ($SpO_2 \geq 92\%$). The institutional review boards of the University of Cincinnati (OH) and Wright-Patterson Air Force Base (OH) approved the study.

3.2 Setting and Participants

This trial was conducted in the emergency department (ED) of the region's only adult Level I trauma center between June 18 and December 31, 2013. The ED is continuously staffed with clinical study assistants who screen patients for inclusion into clinical research. Eligible subjects were adults transported directly to the ED from the scene of injury and who met our institution's highest trauma-team activation criteria. Subjects were excluded if they were transferred from another hospital, younger than 18 years old, or on prescribed, chronic home oxygen therapy for a preexisting condition. Subjects with trauma-team activation more than 30 minutes after ED arrival were also excluded.

3.3 Study Procedures

All clinical care, including use of supplemental oxygen, was at the discretion of the treating physicians. Much of the care for these patients is protocolled and includes standard non-invasive hemodynamic monitoring, continuous pulse oximetry, and laboratory studies. Current ED treatment guidelines advise use of the minimal amount of supplemental oxygen needed to maintain peripheral oxygen saturation (SpO_2) $\geq 92\%$. Protocols also exist for the care of mechanically ventilated patients.

Clinical study assistants responded to the bedside of eligible subjects and recorded supplemental oxygen use, flow rate, and SpO_2 every 5 minutes. Observations ended at the earliest of these time points: after 3 hours of monitoring, discharge from the ED, or admission to the operating room. For admitted subjects, monitoring continued for the full 3 hours.

Clinical study assistants collected prehospital and treatment data while the patient was in the ED. A structured chart review of enrolled subjects was performed to obtain in-hospital data and disposition; charts underwent dual abstraction and dual data entry with adjudication and used structured case report forms and a data dictionary consistent with best methodologies [11]. The institution's Trauma Registry was queried for final injury diagnoses, Abbreviated Injury Scale (AIS) scores, and total Injury Severity Scores (ISS). The medical record and Social Security Death Index were queried at least 6 months after enrollment to determine mortality status.

3.4 Outcome Measurements

The primary outcomes were the proportion of subjects requiring supplemental oxygen and the oxygen flow required to treat hypoxemia ($SpO_2 < 92\%$) in trauma patients at the end of study observation. This outcome was chosen to allow safe titration off possibly inappropriately applied supplemental oxygen in the prehospital setting or upon ED arrival. Supplemental oxygen flow rates were categorized in liters per minute (LPM) as <4 LPM (low flow) or ≥4 LPM (high flow), based on the flow rates able to be generated by chemical oxygen generators and concentrators. Secondary outcomes were oxygen use practices during the period of observation and evaluation of associations between subjects' injury characteristics and oxygen requirements to identify those most at risk for requiring oxygen.

3.5 Sample Size

This was an observational study to determine the supplemental oxygen requirements of trauma patients, and subjects were enrolled over a defined time interval. The target enrollment was at least 100 subjects so that the 95% confidence intervals (CIs) of the proportion of patients requiring supplemental oxygen would extend no more than ±10%.

3.6 Data Management and Analysis

Paper case report forms were entered into REDCap, a secure web-based data management interface. All statistical analyses were conducted using SPSS 22.0 (IBM Corporation, Armonk, NY). The primary outcome is reported as proportions with 95% CIs. Secondary outcomes are reported as risk ratios with 95% CIs.

4.0 RESULTS

4.1 Study Population

A total of 205 eligible subjects provided consent; 204 are included in the analysis (Table 1). One consented subject was admitted to the operating room (OR) within 5 minutes of starting study observation and excluded because oxygen data were not collected.

Table 1. Enrollment

Item	No.
Patients screened	549
Exclusion criteria met	123
Inter-facility transfer	84
Trauma team activation >30 min after arrival	11
Non-English speaking	12
<18 yr of age	6
Prisoner/police custody	7
Home oxygen therapy	1
Pregnant	1
Unable to provide consent[a]	1
Inclusion criteria met	426
Staff unavailable	152
Refused consent	33
Expired before consent	21
Discharged before consent	15
Patients consented	205
No data collection[b]	1
Patients included	204

[a]Mentally ill.
[b]Patient taken to the operating room within 5 min of observation.

The mean age was 37 (standard deviation (SD) 16), 107/204 (53%) were Caucasian, and 161/204 (79%) were male. The median ISS was 9 (interquartile range (IQR) 1-21) and 119/204 (59%) suffered penetrating injuries. Prehospital and ED life-saving interventions were frequently performed. The majority of subjects were admitted (141/204, 69%), with most going directly to the operating room (35/141) or intensive care unit (ICU) (78/141) from the ED (Table 2).

Table 2. Characteristics, Treatment, and Disposition of Subjects

Item	Value
Age (yr), mean (SD)	37 (16)
Race, n (%)	
Caucasian	107 (52.2)
African-American	95 (46.6)
Other	2 (1.0)
Male, n (%)	161 (78.9)
Penetrating injury, n (%)	119 (58.9)
Arrived via EMS[a], n (%)	180 (88.2)
Arrived intubated, n (%)	21 (10.3)
Initial vital signs, mean (SD)	
Systolic blood pressure (mmHg)	133 (29)
Diastolic blood pressure (mmHg)	83 (21)
Heart rate (bpm)	97 (24)
Respiratory rate (bpm)	20 (6)
Oxygen saturation (%)	97 (4)
Initial GCS[a] (total), median (IQR)	15 (13-15)
ISS[b], median (IQR)	9 (1-21)
ISS 15+, n (%)	66 (33.2)
Chest AIS 2+, n (%)	49 (24.6)
Prehospital/ED life-saving interventions, n (%)	
Endotracheal intubation	48 (23.5)
Blood products	35 (17.2)
Hypertonic saline	14 (6.9)
Intraosseous access	8 (3.9)
Thorocostomy	7 (3.4)
CPR[a]	4 (2.0)
Tourniquet	3 (1.5)
Pelvic binding	3 (1.5)
Admitted, n (%)	141 (69.1)
ICU	78 (55.3)
OR	35 (24.8)
Medical floor	28 (19.9)
OR in first 24 h	72 (51.1)
ICU stay in first 24 h	99 (70.2)
Hospital disposition, n (%)	
Home	73 (51.8)
Long term acute care	54 (38.3)
Died in hospital	14 (9.9)
Dead at 30 days (n=204)	14 (6.9)

[a]EMS = emergency medical services; GCS = Glasgow Coma Scale; CPR = cardiopulmonary resuscitation.
[b]n=199.

Twenty-one subjects arrived intubated, and four additional patients were intubated within 5 minutes of ED arrival. Twenty-three subjects were intubated later for a total of 48 subjects intubated, overall. Two subjects were extubated in the ED.

Overall, 142/204 (70%) had at least one indication for oxygen. Multiple indications for supplemental oxygen were possible. Indications for supplemental oxygen included 111/204 (54%) with a documented SpO_2 <92%, 68/204 (33%) with clinical concern for traumatic brain injury (GCS <15 or clinical suspicion), 48/204 (24%) who underwent endotracheal intubation, and 53/204 (26%) with hemorrhagic shock (systolic blood pressure (SBP) <90 or blood transfusion). There were 33/142 (23%) patients with an indication for supplemental oxygen who never received oxygen, and there were 13/62 (21%) who received supplemental oxygen without any indication.

4.2 Primary Outcome

On final observation, 89/204 (44%, 95% CI 37-51%) were on oxygen: 44/44 intubated and 24/160 non-intubated subjects were on ≥4 LPM oxygen; 21/160 non-intubated subjects required <4 LPM (Figure 1). There were 98/204 (48%, 95% CI 41-55%) who were on room air throughout observation. The matrix in Figure 2 depicts supplemental oxygen usage at the first and last observations.

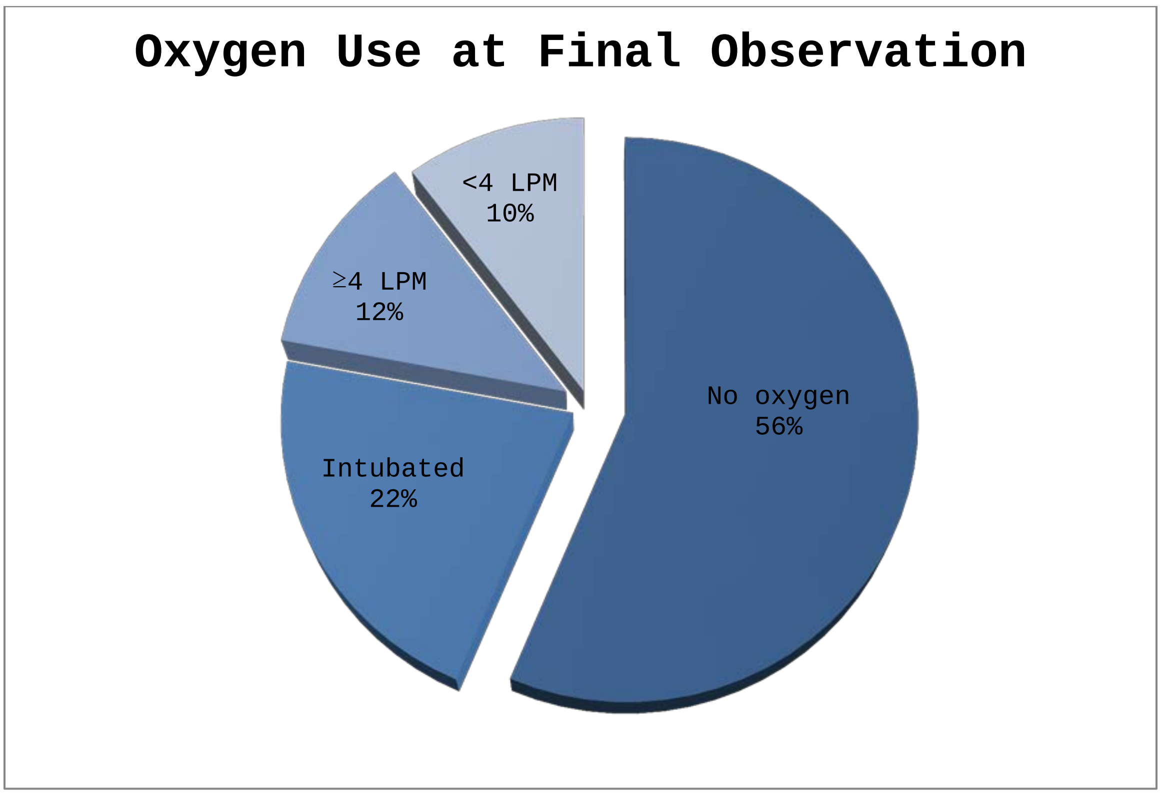

Figure 1. Supplemental oxygen requirements of trauma patients at final observation (n=204).

	Oxygen use at final observation									
	Room Air		<4LPM		>4LPM		Intubated		Total	
Oxygen use at first observation	n	%	n	%	n	%	n	%	n	%
Room Air	101	49.5	11	5.4	6	2.9	6	2.9	124	60.8
<4LPM	2	1	3	1.5	1	0.5	0	0	6	2.9
>4LPM	11	5.4	6	2.9	17	8.3	18	8.8	52	25.5
Intubated	1	0.5	1	0.5	0	0	20	9.8	22	10.8
Total	115	56.4	21	10.3	24	11.8	44	21.6	204	100

Figure 2. Matrix of subjects characterized by supplemental oxygen requirements at first and final observation. Cells in green represent subjects who had decreasing oxygen requirements, while those in red show subjects with increasing oxygen requirements during observation. Some subjects may have had differing requirements during observation (i.e., a subject may have arrived on room air, been placed temporarily on oxygen, and then titrated back to room air by the end of observation). (LPM: liters per minute of supplemental oxygen)

Only 10% of non-intubated subjects were always on oxygen, with at least some use of higher flow rates (Figure 3). The majority of never-intubated patients were managed with low-flow or no supplemental oxygen; 62% never received oxygen, 6% were on some supplemental oxygen at a low flow rate (<4 LPM) during observation, and 2% were always on low-flow supplemental oxygen during observation.

4.3 Secondary Outcome

Table 3 shows factors associated with oxygen need in subjects who were never intubated. Penetrating injuries were less likely to require supplemental oxygen (relative risk (RR) 0.65, 95% CI 0.50-0.84) than other mechanisms of injury. Subjects with a GCS less than 15 were more likely to require supplemental oxygen (RR 2.63, 95% CI 1.22-5.69), but subjects with a head injury (head AIS >1) were not more likely to require oxygen. Hypotension, abdominal injury (abdomen AIS >1), and chest injury (chest AIS >1) were also associated with supplemental oxygen need. There were no factors that differed between subjects requiring high- or low-flow oxygen.

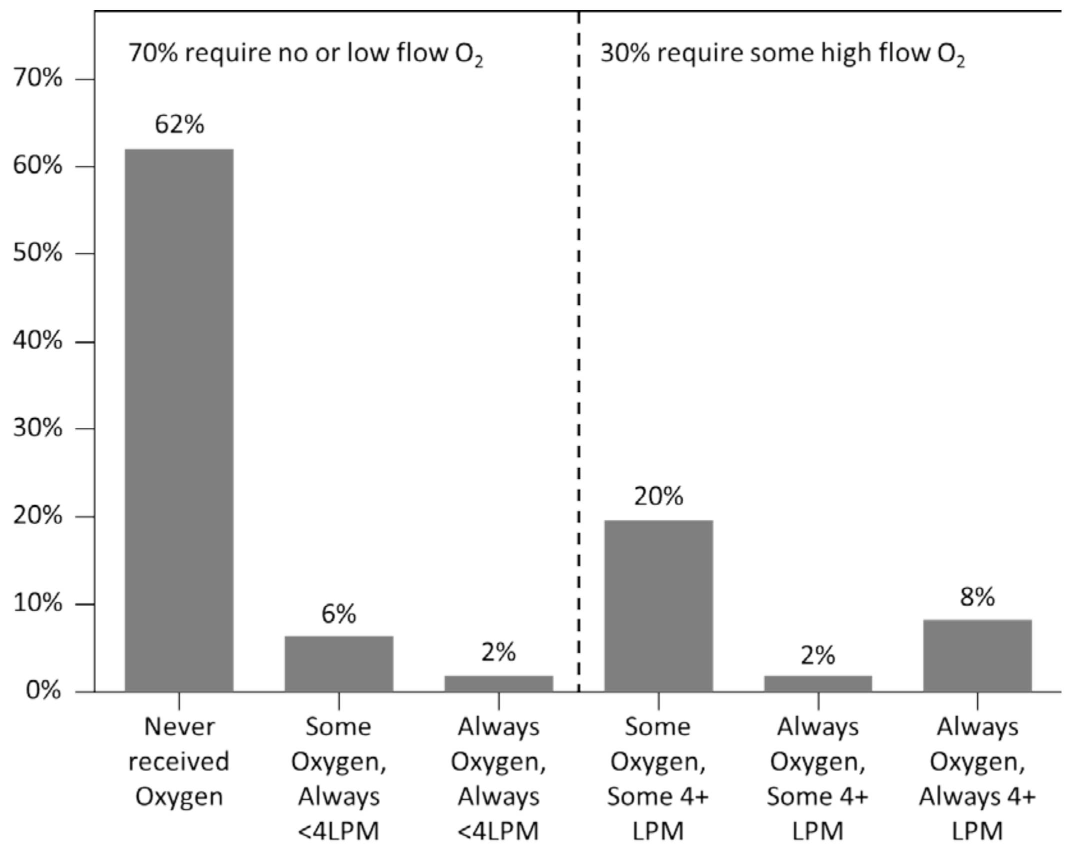

Figure 3. Supplemental oxygen use of never-intubated trauma patients.

Table 3. Risk Ratios for Supplemental Oxygen Use in Never-Intubated Patients (n=156)

Item	Oxygen Use (n=58)		No Oxygen (n=98)		RR	95% CI	
	n	%	n	%		Lower	Upper
Penetrating	24	53.3	88	79.3	0.65	0.50	0.84
Prehospital blood products	0	0.0	1	1.2	1.01	0.99	1.04
GCS < 15	13	28.9	10	9.0	2.63	1.22	5.69
Hypotension (SBP <90 mmHg)	29	64.4	34	30.6	2.11	1.45	3.08
AIS head[a]	7	15.9	8	7.3	2.55	0.96	6.80
AIS chest[a]	17	38.6	10	9.1	7.49	3.00	18.68
AIS abdomen[a]	12	27.3	16	14.5	2.27	1.16	4.45

[a]n=154.

5.0 DISCUSSION

We found that few non-intubated injured adults require high-flow oxygen during the early phases of initial trauma care, and almost two-thirds never required any supplemental oxygen. Those with penetrating wounds were less likely to require supplemental oxygen, while hypotension and truncal injuries were more likely to need oxygen. GCS less than 15, but not head AIS, was associated with oxygen need. Only 15% (24/160) of non-intubated subjects needed high-flow oxygen at the end of observation. These findings have important logistical implications because low flow rates can be supplied by chemical oxygen generators and oxygen concentrators; widespread deployment of high-pressure oxygen cylinders may not be necessary to meet oxygen needs of casualties.

Many (48/204) subjects were intubated during their initial care, and all remained on high-flow supplemental oxygen; this likely reflects local practice patterns of slow oxygen weaning more than true clinical need, thereby limiting our findings in this subset of patients. Based on studies of closed-loop oxygenation of intubated trauma patients, it is plausible that several intubated subjects could have undergone quick oxygen titration to lower flows [12,13]. Interestingly, two subjects intubated prior to hospital arrival were extubated in the ED, and neither required high-flow supplemental oxygen at the end of observation (Table 3).

Empiric use of supplemental oxygen in trauma patients without a physiologic need provides no benefits [14]. Conversely, hyperoxemia has been associated with worsened outcomes in many medical conditions [6,7,15-18] and traumatic brain injury [2,19]. Creation of a clinical prediction tool to discriminate among trauma patients who would benefit from high-flow, low-flow, or no supplemental oxygen would be useful when measures of SpO_2 are not straightforward. Our results provide insight into how such a tool may be developed. Penetrating injuries, GCS <15, thoracoabdominal trauma, and hypotension can be detected in the field and, on univariate analysis, are associated with supplemental oxygen need. Future analyses with larger cohorts will be needed to derive and validate such a clinical tool.

Our findings begin to lay an evidence base for appropriate supplemental oxygen use during early trauma care. Current prehospital trauma life support recommendations require availability of high-flow oxygen to any trauma patient with an abnormal respiratory rate [20]. Based on our data, this results in significant overuse. In the absence of pulse oximetry measurements, patient and injury characteristics may be more useful than respiratory rate alone.

5.1 Limitations

There will always be limitations in application of civilian trauma findings to combat casualty care, but our study was designed to minimize these limitations. Our cohort was young and male, and penetrating trauma was the most common mechanism of injury. Because of tactical body armor, which protects against penetrating head and truncal injuries, our estimates of supplemental oxygen requirements may be conservative. Our hospital is located at approximately 540 feet above sea level; therefore, the impact of altitude-related hypoxemia cannot be evaluated.

5.2 Conclusion

The majority of never-intubated adult trauma patients can be managed with no or low-flow supplemental oxygen. There is significant opportunity to reduce the need for oxygen delivery to the battlespace.

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LIST OF ABBREVIATIONS AND ACRONYMS

AIS	Abbreviated Injury Scale
CI	confidence interval
ED	emergency department
GCS	Glasgow Coma Scale
ICU	intensive care unit
ISS	Injury Severity Score
IQR	interquartile range
LPM	liters per minute
OR	operating room
RR	relative risk
SBP	systolic blood pressure
SD	standard deviation
SpO_2	oxygen saturation, blood oxygen level