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A SIMPLE RESPIRATORY GUIDE FOR RESPIRATORY THERAPY IN THE TRAUMA PATIENT

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Aberdeen Proving Ground, Maryland

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The respiratory index (R.I.), P_{AaDO_2}/P_{aO_2} was investigated in 177 intubated patients treated at the Maryland Institute of Emergency Medicine. An R.I. of 0.1-0.37 is normal. An R.I. of 2 or greater was an indication for intubation, and over 6 was associated with a 12% probability of survival. The R.I. reflects the presence of pulmonary shunting in a variety of circumstances including atelectasis, pulmonary contusion or pulmonary emboli. A nomogram which allows one to follow the course of the patient with respiratory problems is described. Movement along the same

isobars or between isobars can be followed by plotting the P_{aO_2} against the F_{IO_2}. Thus, the rationale and effect of respiratory therapeutic manipulations may be graphically recorded.

SUMMARY

The respiratory index (R.I.), P_{AaDO_2}/P_{aO_2} was investigated in 177 intubated patients treated at the Maryland Institute for Emergency Medicine. An R.I. of 0.1-0.37 is normal. An R.I. of 2 or greater was an indication for intubation, and over 6 was associated with a 12% probability of survival. The R.I. reflects the presence of pulmonary shunting in a variety of circumstances including atelectasis, pulmonary contusion or pulmonary emboli.

A nomogram which allows one to follow the course of the patient with respiratory problems is described Movement along the same isobars or between isobars can be followed by plotting the P_{aO_2} against the F_{IO_2}. Thus, the rationale and effect of respiratory therapeutic manipulations may be graphically recorded.

PREFACE

The work described in this report was authorized under Projects 1E762708A090(EA) Automation of Materiel Concepts-Design, Engineering and Testing: 30B73(LWL) Development of Lightweight Garment; and DAADO573C0032(AMSAA) Research Study of Trauma Patient Data. This work was started in April 1973 and completed in October 1973.

Acknowledgments

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CONTENTS

		Page
I.	INTRODUCTION	5
II.	METHOD	6
III.	RESULTS AND DISCUSSION	6
IV.	RESPIRATORY INDEX NOMOGRAM	9
V.	FUTURE EFFORTS	11
	LITERATURE CITED	13
	GLOSSARY	15
	APPENDIX	17
	DISTRIBUTION LIST	19

A SIMPLE RESPIRATORY GUIDE FOR RESPIRATORY THERAPY IN THE TRAUMA PATIENT

I. INTRODUCTION.

The purpose of this research is to test a respiratory index (R.I.) as an indicator of a trauma patient's respiratory state. If a patient's respiratory state could be simply characterized and followed, this would allow one to: (1) compare therapy in patients with respiratory complications in various institutions, (2) compare variations in treatment, and (3) graphically represent a patient's progress or deterioration as an adjunct to patient care by means of a nomogram described later.

An increase of the alveolar-arterial P_{O_2} difference is a common indicator of hypoxia and is an important consideration in controlling arterial oxygenation in the clinical environment. The alveolar-arterial P_{O_2} difference results from venous admixture (or physiologic shunt) which is caused by (a) shunted venous blood which mixes with oxygenated blood leaving the pulmonary capillaries, and (b) uneven ventilation-perfusion ratios in different parts of the lung.[1,2]

When the patient breathes 100% oxygen the P_{AO_2} may be calculated from:

$$P_{AO_2} = P_B - (P_{aCO_2} + P_{H_2O,T}) = (P_B - P_{H_2O,T}) \times 1.0 - P_{aCO_2}$$

where

P_B = barometric pressure

$P_{H_2O,T}$ = alveolar water vapor pressure at the patient's temperature (T), (approximately 47 mm Hg)

F_{IO_2} = fractional concentration of O_2 in inspired gas

P_{aCO_2} = arterial partial pressure of carbon dioxide assumed to be equal to the alveolar partial pressure of the carbon dioxide (P_{ACO_2}).[3]

The above equation permits one to calculate the alveolar-arterial oxygen difference at different inspired oxygen concentrations, between 20% and 100%. The alveolar-arterial difference was then divided by the P_{aO_2} so that the respiratory index (R.I.) equals:

$$\frac{[(P_B - P_{H_2O,T})F_{IO_2} - P_{aCO_2}] - P_{aO_2}}{P_{aO_2}} = \frac{P_{AaDO_2}}{P_{aO_2}} = \text{R.I.}$$

This calculation was suggested to the investigators by J. H. Siegel.*[4] Since the P_{AaDO_2} reflects shunting, the R.I. would also reflect pulmonary shunting. And this paper will indicate the usefulness

* Siegel, J. H. Personal Communication.

of the R.I. when a patient's respiratory pathophysiology involves shunting. These conditions include pulmonary contusion, pulmonary embolus, and atelectasis caused by bronchial obstruction, mechanical compression of the lung or hypoventilation.[3]

II. METHOD.

The patients evaluated here were all treated at the Maryland Institute for Emergency Medicine. Most patients were trauma victims and were delivered by helicopter from the scene of the accident between March 1971 and August 1972. Of the primary types of insults, 71.8% incurred blunt trauma, 7.3% gunshot wounds, 2.8% burns, 5.1% elective surgical problems, and 13.0% medical problems. Of the trauma group, with regard to major areas affected, 27.4% had central nervous system injury, 25.4% thoracic injury, 17.9% abdominal injury, 17.5% musculoskeletal trauma, and 11.9% head injury. Patients listed usually had one or more of the above injuries.

The patients included here were in the unit at least two days. They represent patients who had the F_{IO_2} recorded throughout their therapy. This means that the patient was intubated at least once during his hospital course and placed on the Engstrom Respirator. The Engstrom Respirator was used in every case when the patient required assisted ventilation. Since the patients were on Engstrom Respirators, one could calculate the percent 0_2 administered by plotting the liters per minute of 0_2 against the total minute volume in liters per minute. This graph accompanies all Engstrom Respirators. Arterial blood gases were measured every time the therapy of F_{IO_2} was altered. Arterial blood gases were also measured at least every 6 hours in every intubated patient.

III. RESULTS AND DISCUSSION.

A. Respiratory Index Data and Associated Probabilities of Survival.

The accompanying retrospective statistics in table I represent a total of 177 patients, where 116 lived and 61 died. The upper limits of normal alveolar-arterial differences (on room air) for ages 20, 40, and 60 are 19 mm Hg, 24 mm Hg, and 28 mm Hg. The lower limits for P_{aO_2} (on room air) for those age groups are 85 mm Hg, 80 mm Hg, and 75 mm Hg. Dividing the alveolar-arterial difference by the P_{aO_2} the respiratory indices are 0.22, 0.3 and 0.37, respectively.[5] In every case when the R.I. was as high as 2, the patient was intubated. This is understandable since an R.I. of 2, with the patient on room air (20% oxygen), and a P_{aCO_2} of 35 mm Hg would mean that the patient would have a P_{aO_2} of 37 mm Hg. The R.I.'s listed represent the maximum R.I.'s of the patients' entire hospital stay (table I). The R.I. probabilities are generated from the group of patients treated at the Maryland Institute for Emergency Medicine. The probabilities should be expected to change somewhat depending upon the therapy at a particular institution.

When the pathology was reviewed, a major disorder in 51 out of 116 survivors was central nervous system damage usually due to head trauma. Twenty nine out of 61 patients who died also had major CNS trauma. *Brain death* secondary to a CNS injury was most important in the group that died with and R.I. under 4. There were 16 patients with CNS injury among the 22 patients that died with an R.I. under 4. The other six patients that died with an R.I. under 4 died of

Table I. Frequency Charts for Maximum Respiratory Index

Maximum Respiratory Index (R. I.)	Total Number of Patients (Lived)	Patients that Lived without CNS Injury	Total Number of Patients (Died)	Patients that Died without CNS Injury
(0-1)	33	19	2	0
(1-2)	23	15	6	2
(2-3)	21	12	8	1
(3-4)	16	8	6	3
(4-5)	12	6	7	6
(5-6)	8	2	7	5
(6-7)	2	2	5	3
(7-8)			6	5
(8-9)			5	1
(9-10)			3	3
(10-11)	1	1	3	2
(11-17)			3	1
TOTAL	116	65	61	32

sepsis and/or cardiac arrhythmias. Respiratory pathology did not appear to be a major factor in their demise. The patients with CNS injury that died with a low R.I. (under 2) had a median time to death of 5 days. These patients did not enter with, nor develop, clinically significant respiratory complications. The patients with CNS injury and an R.I. from 2 to 4 had a median time to death of 10 days. They also died primarily a brain death, but frequently had intercurrent pneumonia or associated thoracic or abdominal injury, leading to pulmonary shunting and a higher R.I.

Of the entire group of patients that died with an R.I. over 5, pulmonary pathology was always an important element in their demise. There was only one patient that lived with an R.I. over 7. This patient had an R.I. of 10.5 for a brief time subsequent to a bilateral pneumothorax secondary to positive and expiratory pressure (PEEP). Once the pneumothoraces were treated, the patient's R.I. slowly returned to normal. Eight patients survived with an R.I. between 5 and 6, and only two survived with an R.I. between 6 and 7. Thus, 11 patients survived with an R.I. over 5. On the other hand, 32 of the 61 patients that died had an R.I. of 5 or greater. The probability of survival with an R.I. over 5 was 26% and an R.I. over 6 was associated with a 12% probability of survival. Other survival probabilities are listed in table II. It should be stressed that the reliability of the R.I. is enhanced by its irreversibility. For example, even if the R.I. is over 6 and then returns to normal with treatment over the next several days, the patient appears to have the same poor probability of survival. In addition, in one-half of the patients with an R.I. greater than 5 their highest measurements were recorded at least 1 day prior to the day of death.

Table II. Histograms for Maximum Respiratory Index

Maximum Respiratory Index (R.I.)	Probability of Survival for Total Number Of Patients	Probability of Survival For Patients without CNS Injury
(0-1)	0.95	0
(1-2)	0.8	0.89
(2-3)	0.73	0.93
(3-4)	0.73	0.73
(4-5)	0.64	0.49
(5-6)	0.55	0.28
≥ 5	0.26	0.2
≥ 6	0.12	0.18
Information Gain	0.20*	0.29*

* See Appendix

IV. RESPIRATORY INDEX NOMOGRAM.

In order to track respiratory therapy graphically for this group of 177 patients, a nomogram was designed(figure). Respiratory index isobars were calculated with varying P_{aO_2} and percent 0_2 administered, but with a constant P_{aCO_2} of 35 mm Hg. The variations in R.I. with a P_{aCO_2} of 20 mm Hg or 60 mm Hg instead of 35 mm Hg have been calculated. For example, if the patient is on 40% 0_2, and the P_{aO_2} is 100 mm Hg, and the P_{aCO_2} ranges from 20 mm Hg to 35 mm Hg to 60 mmHg the corresponding R.I.'s are 0.3, 0.15, and 0.10. This variation decreases as the R.I. increases. For a closer approximation, one can add 0.2 R.I. units for every 15 mm Hg decrease in P_{aCO_2} from a P_{aCO_2} of 35 mm Hg and subtract 0.2 R.I. units for every 15 mm Hg increase in P_{aCO_2} above 35 mm Hg.

In order to explain the use of this graph consider a typical patient with thoracic trauma. The patient is a young adult who incurred fractures of ribs, 3, 4, 5, 6, 7, and 8 on the left side. This represents an example of blunt chest trauma with a lung contusion. Twenty minutes after the accident the P_{aO_2} is 50 mm Hg, P_{aCO_2} 35 mm Hg, and arterial blood pH 7.3 while on room air (point A). The graph indicates that the patient is on an R.I. isobar of about 1. The patient then begins to have respiratory muscular splinting and is breathing at 20 times per minute. He is given 30% oxygen by mask. Repeat measurements of blood gases show a P_{aO_2} of 55 mm Hg, P_{CO_2} 35 mm Hg, and arterial blood pH 7.4; the patient moves to the 2.0 R.I. isobar (point B). At this point the patient should be intubated. In this example he is placed on 40% oxygen on a respirator. The P_{aO_2} is now 120 mm Hg and the R.I. is again 1 (point C). He has, therefore, moved from an R.I. of 2 to 1, indicating an improved respiratory status secondary to therapy. If a repeat P_{aO_2} is 205 mm Hg, the patient would be on 0.2 isobar (point D), indicating further improvement. If repeat P_{aO_2}, however, is 58 mm Hg, the patient's condition would have deteriorated and he would now be on the 3.0 R.I. isobar (point E). In the instance when the P_{aO_2} is 205 mm Hg, one might place the patient on 20% O_2 on a respirator which should give a P_{aO_2} of 90 mm Hg, assuming the patient remains on the 0.2 R.I. isobar (point F). If the P_{aO_2} drops to 58 mm Hg, a change of therapy is obviously indicated. One course might be increasing the administered O_2 to 60% which should give a P_{aO_2} of 90 mm Hg (point G). If the P_{aO_2} has not increased to at least 90 mm Hg on 60% O_2 (indicating an R.I. of 3), end expiratory pressure should be added to the regimen. If the P_{aO_2} drops from 90 mm Hg to 70 mm Hg on a 60% O_2, PEEP would also be indicated. It should be noted that there is miminal increase in P_{aO_2} once a patient is on the R.I. 3 isobar. Here, if the patient is on 60% O_2 and the P_{aO_2} is 90 mm Hg (point G), placing the patient on 100% O_2 would give a P_{aO_2} of 160 mm Hg (point H). The amount of increase in the P_{aO_2} decreases as the slopes of the isobars decrease. This reflects the generally accepted notion that if a patient is sufficiently ill to require 60% F_{IO_2}, increasing the F_{IO_2} beyond 60% does not effect much of an increase in P_{aO_2}. In addition, the risk of oxygen toxicity is a hazard when the patient is placed on high concentrations for long periods.[2]

The R.I. in certain cases could also inform the physician that the respirator is not working properly. If any patient is supposedly breathing 30% O_2, and his P_{aO_2} were 220 mm Hg, he would have an R.I. less than O, which is impossible. This would indicate that the F_{IO_2} was

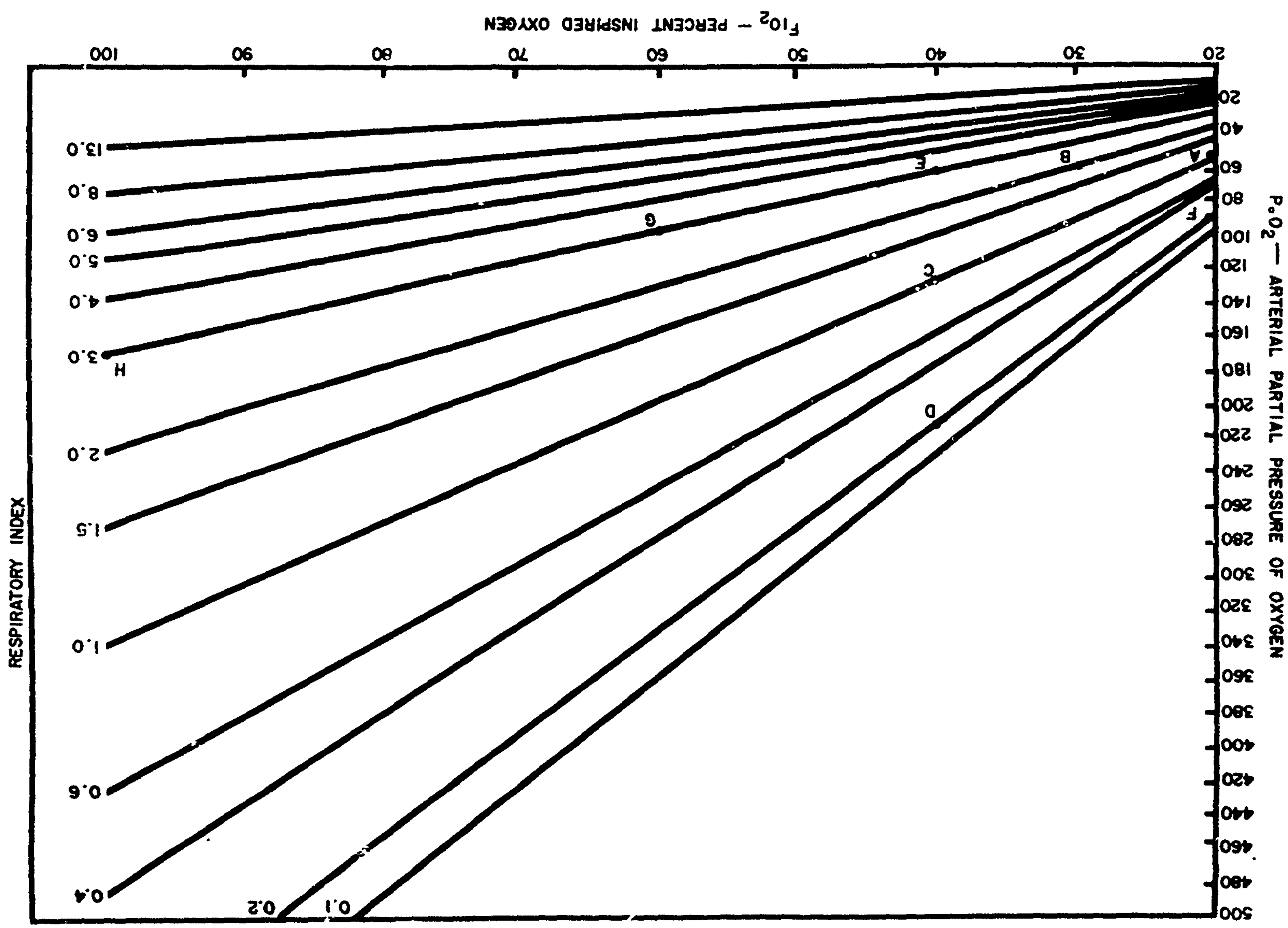

Figure. Nomogram for Respiratory Therapy actually greater than 30% and probably at least 40%. In several intubated patients, therapy included limited periods of 100% O_2 administration, particularly when calculating the pulmonary shunt. Here, one noted that the typical patient remained near the same isobar as the amount of O_2 administered changed from 40% to 100% and back to 40%.

V. FUTURE EFFORTS.

There are several areas of research that require further investigation with regard to the respiratory index. They include:

1. Testing the R.I. with data from trauma patients in a prospective fashion. Subgroups of trauma patients may clarify the prognostic significance of respiratory pathology in cases of isolated thoracic trauma, multiple trauma including the thorax, the multiple trauma excluding the thorax. The relevance of the R.I. in pulmonary units (nonsurgical) should prove helpful with regard to those cases with significant shunting, and deserves implementation.

2. The applicability of the nomogram will be tested further by the physicians handling respiratory problems as a graphic representation of the trend of various forms of respiratory pathology with alterations in therapy.

3. The prognostic and therapeutic value of the R.I. must be compared with more complex pulmonary indices including percent pulmonary shunting, pulmonary compliance, and expiratory reserve volume, etc. Such indices may perhaps be added to the R.I. to characterize even more precisely and collate respiratory pathophysiology.

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GLOSSARY

P_{AO_2}	Partial pressure, alveolar, of oxygen
P_B	Barometric pressure
P_{aCO_2}	Arterial partial pressure of carbon dioxide assumed to be equal to the alveolar partial pressure of the carbon dioxide
$P_{H_2O,T}$	Alveolar water vapor pressure at the patient's temperature (T) approximately 47 mm Hg
F_{IO_2}	Fractional concentration of O_2 in inspired gas
P_{aO_2}	Partial pressure, arterial, of oxygen
P_{AaDO_2}	Alveolar-arterial partial pressure of oxygen difference
PEEP	Positive and expiratory pressure

APPENDIX

INFORMATION GAIN

A measure of the information inherent in an index is called the "information gain". It has the following interpretation: Suppose an Intensive Care unit manages to save 80% of their patients. The probability of survival, P_L, of an arriving patient is, therefore, 0.8. If the physician is given additional information about a particular patient, he might be able to alter the prognosis from 0.8 to 0.2. The gain in information between probabilities would be the difference before and after the additional input. More specifically, with the total group of patients in this study, the average information gain is 0.2 with respect to the lived-died statistics of intubated patients. For the group of patients without CNS injury the average information gain is 0.29. Let x designate the index to be evaluated. Then the average information gain, I, is

$$I = \sum_{i=1}^{n} \left| P_L - P(L|x \text{ is in bin } i) \right| [\text{Probability that } x \text{ is in bin } i]$$

where

P_L is the prior probability that a patient will live, and

$P(L|x$ is in bin $i)$ is the conditional probability that a patient will live given that index x belongs to bin i.*

The information gain may also be used to test any other parameter which one may want to include to enhance the validity of a prognosis. The information gain analysis would indicate the value of the new parameter.

* Sacco, W. J. and Copes, W. S. Reduction of the Class of Feature Evaluation Techniques of Pattern Analysis. Pattern Recognition *4*, 331-332 (1972).