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Research Article

Estimation of Oxygen Pressure in Arterial Blood from Pulse Oximetry: A Useful Out-of-hospital Tool

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Abstract

Background In out-of-hospital emergency, there are obvious limitations for therapeutic decision-making due to the lack of complementary tests that are available in the hospital environment, including the value of arterial oxygen pressure (PaO_2) using arterial blood gas as It helps in assessing the severity of patients with Acute Respiratory Failure.

Methods Obtain PaO_2 equivalency values from integer SaO_2 values on the measurement scale between 1% and 100%, and set the SaO_2/FiO_2 intervals associated with severity levels in acute respiratory failure (ARF) hypoxemic. Mathematical analysis by inversion of the function of the Hemoglobin Dissociation Curve at physiological values of pH=7.4 and T^a=37°C, to obtain the equivalent values of PO_2 in arterial blood from integer values of SpO_2 obtained by pulse oximetry.

Results A correspondence table was obtained between SaO_2 and PaO_2 as well as the SaO2/FiO2 intervals equivalent to those of PaO_2/FiO_2 according to severity levels in patients with hypoxemic ARF with FiO_2=21%.

Conclusions SpO_2, in the absence of PaO_2, is useful in establishing the severity of patients with hypoxemic ARF in emergency situations.

Keywords: Transcutaneous Oximetry; Respiratory Insufficiency; Emergencies

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Introduction

In out-of-hospital emergency, there are obvious limitations for therapeutic decision-making due to the lack of complementary tests that are available in the hospital environment, including the value of arterial oxygen pressure (PaO_2) using arterial blood gas(1) as It helps in assessing the severity of patients with Acute Respiratory Failure (ARI). The arterial saturation of hemoglobin by oxygen (SaO_2) is considered the fifth vital sign, and should be measured by pulse oximetry (SpO_2) and always taken into account, along with the inspired fraction of oxygen (FiO_2) that the patient receives. at the time of SpO_2 measurement, in all those with dyspnea in the context of an acute crisis(2).

The ratio between PaO_2 and FiO_2 or Kirby index(3), usually represented by the expression PaO_2/FiO_2, and its correlation with the severity levels of the patient with ARF is well established according to the Berlin Definition(4).

Blood oxygen monitoring should be carried out when and where it is most beneficial to the patient; that is, although the laboratory can provide greater precision, sometimes, due to clinical necessity, it will be necessary to perform it in the out-of-hospital setting to make quick decisions that

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benefit to the severe patient in a therapeutic emergency situation(5). Taking into account the benefits and limitations of each technique, we must assess pulse oximetry in situations that advise it(6) since a good correlation between SaO_2 and SpO_2(7) as well as between SpO_2 and PaO_2(8) has been demonstrated in patients with ARF, and the ratio of PaO_2/FiO_2 may be substituted by that of SpO_2/FiO_2 as a measure of oxygenation since it has also shown a good correlation(9,10).

The correlation between PaO_2 and SaO_2 is established by the oxy-hemoglobin (ODC) dissociation curve (Figure 1). Roughton and Severinghaus(11) compiled in 1973 the data necessary to relate PaO_2 and SaO_2 from which, by means of the Hill equation and the addition of a cubic function at the base of the curve, the graph representing in two axes the ODC. This correlation, and despite the fact that there are certain ions and molecules that, depending on the intensity of their presence in the blood, can shift the curve to the left or to the right(5), it is sufficiently robust and reliable to serve as a reference, in non-optimal conditions, in out-of-hospital emergency when laboratory data are not available; however, for easier handling it would be of interest to invert the curve and obtain equivalence tables from integer SpO_2 values as obtained from pulse oximetry measuring devices, and relate them to their PaO_2 equivalent.

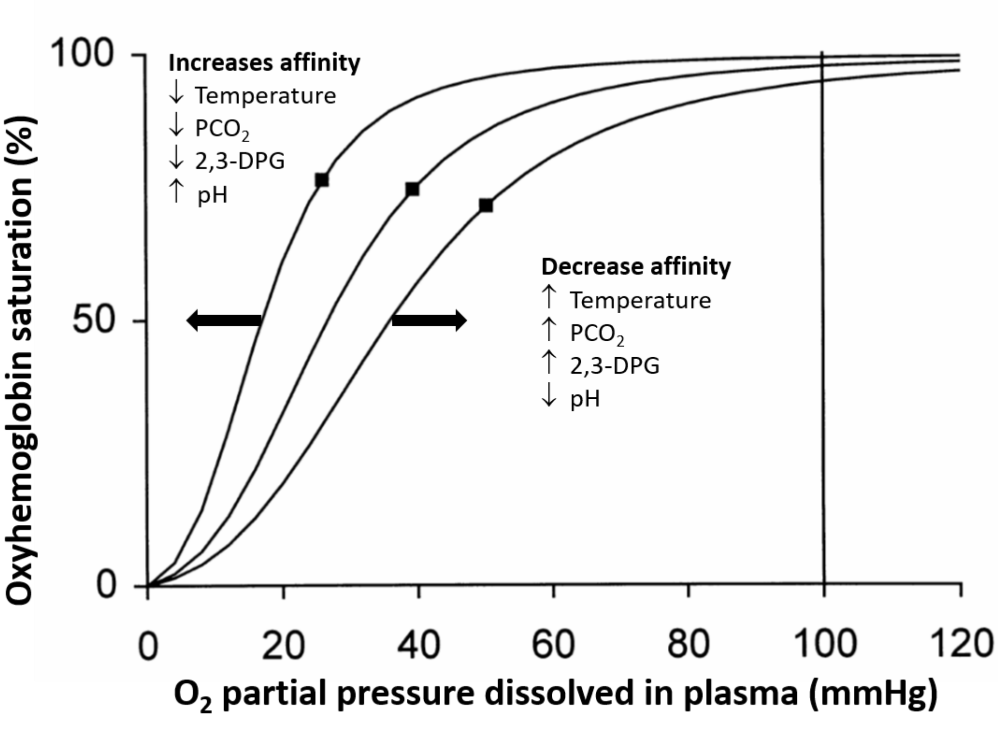

Figure 1. Hemoglobin dissociation curve according to the presence of ions and molecules. Modified from Morgan TJ(12)

The main objective of this study was to obtain the equivalence values in PaO_2 from the integer values of SpO_2 on the measurement scale between 1% and 100%, by reversing the ODC calculated by mathematical models, and secondarily establishing the SpO_2/FiO_2 intervals associated with severity levels in the ARF.

MATERIAL AND METHODS

Mathematical analysis study by inversion of the function of the dissociation curve of oxy-hemoglobin in arterial blood at physiological values of pH=7.4 and T^a=37°C, to obtain the equivalent values of PO_2 in arterial blood from of integer values of the percentage of SpO_2 obtained by pulse oximetry.

Normally, arterial oxygen pressure is usually expressed as a function of arterial oxygen saturation of hemoglobin, as shown in equation [1], described in the work published by Severinghaus(11)

$$SaO_2 = \frac{1}{\frac{23400}{(PaO_2)^3 + 150PaO_2} + 1}, \qquad [1]$$

$$SaO_2 \in [0,1]$$

This function can be inverted, so that for the set of values of S we can obtain PO_2. Developing the expression [1], we are left with the following reduced cubic equation

$$(PaO_2)^3 + 150PaO_2 - \frac{23400SaO_2}{1 - SaO_2} = 0$$

The equation can be solved by Cardano's method, described in his work "Ars Magna". For this we must find u and v such that

$$u - v = \frac{23400SaO_2}{1 - SaO_2} \qquad [2a]$$

$$uv = \left(\frac{150}{3}\right)^3 \qquad [2b]$$

If we clear u from equation *[2a]* and substitute into equation *[2b]* we are left with

$$\left(\frac{23400SaO_2}{1 - SaO_2} + v\right)v = 50^3 \qquad [3]$$

Developing the expression, we obtain that

$$v = -\frac{11700SO_2}{1 - SaO_2} + \sqrt{\left(\frac{11700SaO_2}{1 - SaO_2}\right)^2 + 50^3} \qquad [4]$$

In consequence,

$$u = \frac{11700SaO_2}{1 - SaO_2} + \sqrt{\left(\frac{11700SaO_2}{1 - SaO_2}\right)^2 + 50^3} \qquad [5]$$

Being

$$PaO_2 = u^{\frac{1}{3}} - v^{\frac{1}{3}} \qquad [6]$$

The inverted function sought is

$$PaO_2 = \left(\sqrt{\left(\frac{11700SaO_2}{1 - SaO_2}\right)^2 + 50^3} + \frac{11700SaO_2}{1 - SaO_2}\right)^{\frac{1}{3}} - \left(\sqrt{\left(\frac{11700SaO_2}{1 - SaO_2}\right)^2 + 50^3} - \frac{11700SaO_2}{1 - SaO_2}\right)^{\frac{1}{3}} \qquad [7]$$

And, therefore, obtaining the graphs represented in Figure2.

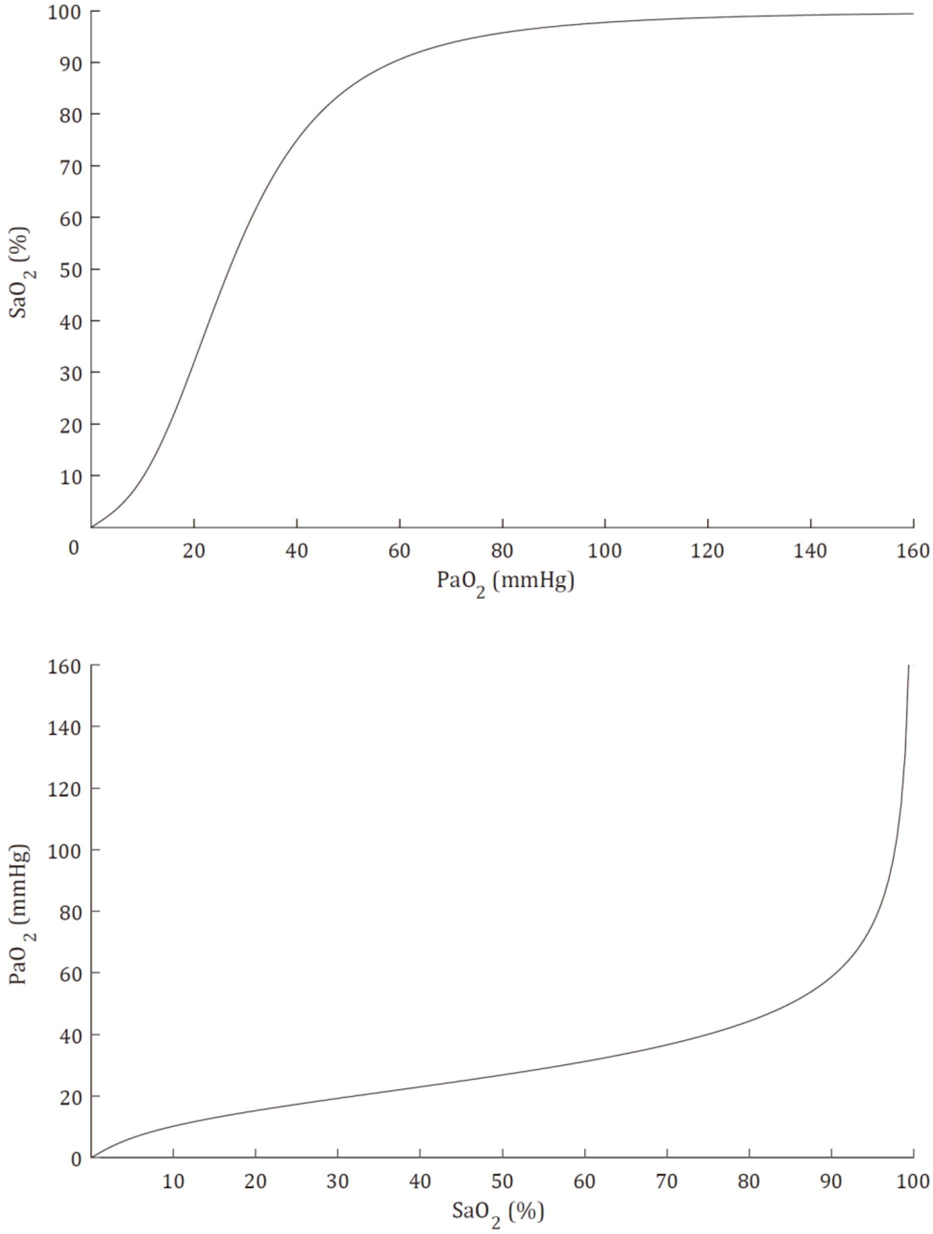

Figure 2. Top image: SaO*2* increase curve from the increase in PaO_2 values in blood, obtained according to equation *[1]*; Lower image: Inversion of the SaO*2* increase curve from the increase in PaO_2 values in blood, obtained according to equation *[7]*

Results

The values obtained for PaO_2 corresponding to each of the integer values in percentage of SaO_2 between 1% and 100% are presented in Table 1 and can be seen in the column next to each of the SaO_2 value.

Table 1. Integer values of SaO$_2$ (%) and their PaO$_2$ equivalents (mmHg).

SaO$_2$	PaO$_2$	SaO$_2$	PaO$_2$	SaO$_2$	PaO$_2$	SaO$_2$	PaO$_2$
1	1,55	26	17,72	51	27,26	76	40,81
2	3,00	27	18,11	52	27,68	77	41,62
3	4,30	28	18,49	53	28,09	78	42,47
4	5,43	29	18,88	54	28,52	79	43,36
5	6,43	30	19,26	55	28,95	80	44,30
6	7,33	31	19,63	56	29,39	81	45,30
7	8,14	32	20,01	57	29,83	82	46,36
8	8,89	33	20,38	58	30,28	83	47,49
9	9,58	34	20,76	59	30,74	84	48,71
10	0,22	35	21,13	60	31,22	85	50,01
11	10,82	36	21,50	61	31,70	86	51,43
12	11,40	37	21,87	62	32,19	87	52,97
13	11,95	38	22,24	63	32,69	88	54,67
14	12,47	39	22,62	64	33,21	89	56,55
15	12,97	40	22,99	65	33,74	90	58,66
16	13,46	41	23,37	66	34,28	91	61,04
17	13,93	42	23,74	67	34,84	92	63,79
18	14,39	43	24,12	68	35,41	93	67,01
19	14,83	44	24,50	69	36,01	94	70,87
20	15,27	45	24,89	70	36,62	95	75,67
21	15,69	46	25,27	71	37,25	96	81,90
22	16,11	47	25,66	72	37,91	97	90,57
23	16,52	48	26,06	73	38,59	98	104,19
24	16,93	49	26,45	74	39,30	99	131,94
25	17,33	50	26,86	75	40,04	100	> 677

The Berlin Definition(4) establishes the severity ranges for Acute Respiratory Distress Syndrome (ARDS), based on the degree of hypoxemia in: mild, moderate and severe; we calculated their equivalence in SaO_2/FiO_2 for a patient breathing ambient air at sea level (21% of FiO_2) from our Table 1 of results; the obtained values are shown in Table 2.

Table 2. SaO_2/FiO_2 values equivalent to the severity levels for hypoxemia in ARDS according to the Berlin Definition (calculations based on a FiO_2 of 21%).

Berlin Definition		**Calculate equivalents**
Severity levels	**PaO_2/FiO_2**	**SaO_2/FiO_2**
No respiratory failure	> 300	> 438
Mild	200 - 300	367 - 438
Moderate	100 - 200	167 - 367
Severe	< 100	< 167

DISCUSSION

The aim was to make the PaO_2 values equivalent to those of monitored SpO_2 readily accessible, being able to be very useful in those emergency times when arterial blood gas is not available, but when it is necessary to make quick decisions with limited resources inherent to out-of-hospital treatment to be applied, in cases where CO_2 values can be ignored(7).

The curve that represents the oxygen dissociation of hemoglobin has been extensively studied and its formulation complex; at the top of the curve, when the 70 mmHg of O_2 tension is exceeded, it has an asymptotic behavior approaching the limit value, while below 60 mmHg the curve is steep, falling rapidly to a turning point in around 20 mmHg, making its fall smoother(13), giving it its sigmoidal configuration. One of the first mathematical descriptions of the ODC is the equation proposed by Hill in 1910(14), which was subsequently revised and modified by Severinghaus(11). To meet our objective, it was necessary to invert the ODC in order to calculate the exact PaO_2 value from integer saturation values, between 1% and 100%, that the pulse oximeter yields.

The curves, depending on the intensity with which the presence of certain ions, molecules and conditions in the blood, present deviations of the ODC with respect to the normal curve, at P50, the way in which the deviations must be measured; in this case, the PO_2 that corresponds to 50% of SaO_2(15); thus, temperature, CO_2, 2-3 diphosphoglycerate and pH influence the shift to the left or the right of ODC, increasing the affinity of hemoglobin for oxygen when it moves to the left (decrease in P50) and decreasing it when the shift is to the right (increase in P50). We have made our calculations under ideal conditions for a curve without deviation, so it could be the case that, on several occasions, the correspondence in PaO_2 with respect to the SpO_2 measured was not the one indicated in Table 1; however, we consider that the deviations are not important enough that the calculations made are not useful and not taken into account when the urgency requires it; In addition, pulse oximetry has been shown to be sensitive, and moderately specific, in the initial evaluation, on arrival at the emergency department, of patients with an ineffective respiratory pattern(8).

Study limitations

This work has been limited by mathematical calculations exclusively, without taking into account the influence of the other variables that affect the ODC to a greater or lesser degree. It is, therefore, an approximation to the interpretation of SpO_2 in an area where urgency requires it and laboratory data are not available for more precise decision-making.

In conclusion, SpO_2 can be used, when laboratory blood gas values are not available, to establish the severity of patients with hypoxemic ARF in situations where the emergency requires immediate decision-making. The integer values of SpO_2, as collected from the pulse oximeter, have obtained their correspondence in PaO_2 as reflected in our results, which also enables us to establish the levels of severity equivalent to the Berlin Definition in SpO_2/FiO_2.

Conflicts Of Interest

None

Acknowledgments

None

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