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Oxygen parameters of blood: definitions and symbols

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Definitions and symbols for relevant parameters of the oxygen status of arterial blood are recommended. The recommendations are as simple as possible, easy to understand, and devoid of misinterpretations and double meanings. The authors propose
- no new definitions for limited new methods,
- no combination of symbols and methods, and
- no association between definition, symbol and commercial name.

Key words: Oxygen status; definitions; symbols.

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INTRODUCTION

Despite the ongoing attempt to improve patient safety the very disadvantages of a particular method may often lead to both misinterpretations and mishaps. Therefore, a recognized goal of both clinicians and scientists within the field of medical technology should be the identification of any measured value that has been defined previously, described by a symbol and expressed in special units.

Apparent difficulties to achieve this goal, are continuously demonstrated, e.g. "when there is reason to believe that the values are method-dependent" [5] - i.e. the method obviously has some disadvantages - "a symbol should be associated with a particular method of measurement" [5].

We, in contrast, propose the opposite approach: "The essential point is that physiological quantities should, if at all possible, be defined, independent of the method used to measure them, and that symbols should not suggest otherwise" [10].

Accordingly, definitions and symbols concerning the oxygen status of arterial blood were proposed two years ago, based on established physiological terminology [9].

We wish to suggest a general adoption of that approaches, offering some proposals, some of them are based on earlier recommendations [3,4,8].

GENERAL REMARKS ON SYMBOLS

1. The use of small letters for the symbols "p" (partial pressure), "s" (saturation) and "c" (concentration) (e.g. pO_2, sO_2, cO_2) follows recommendations of the IFCC and IUPAC [4].

   This supports the use of contemporary text systems and mostly eliminates the need to use subscripts (except for chemical valencies: e.g. O_2, CO_2, H_2CO_3, etc.).

   The potential risk of misinterpretations and double meanings is reduced also (e.g. "cO_2" [oxygen concentration] v.s. "CO_2" [carbon dioxide] and "sO_2" [oxygen saturation] v.s. "SO_2" [sulfur dioxide]).

2. The symbol shall include the site of measurement or description, e.g. paO_2 (arterial O_2 partial pressure), $s\bar{v}O_2$ (mixed venous oxygen saturation), or $avDO_2$ (arterio-venous oxygen difference). This removes in an intelligible manner the confusion of symbols (e.g. paO_2: PaO_2, p_aO_2, Pa_{O_2}, $P_{a_{O_2}}$ etc.).

   We wish to question the rationals of a statement as "writing $S_{a_{O_2}}$, $S_{O_2}(a)$, $S_{O_2}(ab)$ or the like, is a matter of taste" [10], because perfect confusion may be the result, here concerning the arterial O_2 saturation (saO_2).

3. It is a convention in chemistry to refer to radicals or compounds containing oxygen with the term "oxi" rather than "oxy" (e.g. carbon monoxide (CO), carbon dioxide (CO_2), oxidized Hb (MetHb) etc.). On the other hand, methods and terms referring to molecular oxygen (oxygenium) should be written with "y" and not with "i" (e.g. oxymetry, pulse oxymetry, oxygenation, Hb with reversibly bound O_2 (Oxy-Hb, O_2Hb) and deoxygenated Hb (Deoxy-Hb, Hb), etc.).

4. Even if a new *in vivo* method differs considerably from the established *in vitro* method (e.g. *in vivo* (transcutaneously) measurement of arterial O_2 saturation or O_2 partial pressure) this does not justify the use of different notations or symbols.

   Use of the symbol $ptcO_2$ should be avoided for transcutaneously determined "paO_2": Either the method is able to measure the arterial pO_2, then the symbol paO_2 should be used. If this is not the case, however, i.e. if indeed the cutaneous pO_2 is determined, then the symbol $pctO_2$ is appropriate.

   The use of Sp_{O_2}, [2,7] or S_pO_2 [5] or $S_{O_2}(po)$ [10] for arterial O_2 saturation, measured by pulse oxymetry, could erroneously suggest the measurement of an essentially different quantity [10].

5. The number of symbols employed for a given measured value should be kept as small as possible. For this reason the suggestions of Payne & Severinghaus [5] should not be followed, since a total of six different symbols is recommended for the O_2 saturation.

   Consequences are a worldwide confusion: within only one article [2] arterial oxygen saturation is referred to as Sp_{O_2} (pulse oxymeter reading), FSa_{O_2} (functional saturation), Sa_{O_2} (fractional saturation), O_2Hb % (fractional saturation). Within the same volume of a journal [2,7] Sa_{O_2} is used for fractional oxygen saturation [2] as well as for functional oxygen saturation [7]. Obviously, the notation "fraction" becomes more and more attractive:

   Besides the wide accepted "fraction" in respiratory physiology (e.g. FIO_2, inspired oxygen fraction), the oxyhemoglobin fraction F_{HbO_2} was proposed [10] for the $S_{O_2}(frac)$ [5] or the fractional saturation Sa_{O_2} [2].

   But, on the other hand, the symbol F was then introduced as FSa_{O_2} for the functional (not the fractional) saturation and used besides the common FIO_2 [2],

the inspired oxygen fraction.

6. Symbols used for any notations should be as simple as possible. Neither the use of NSo_2 to describe the noninvasive technique [1] for the measurement of oxygen saturation, nor that of Sp_{O_2} [2] for pulse oxymetry should be accepted.

7. The symbol for a measured value must be independent of the method (cf. comment 5), and certainly independent of the manufacturer. Recent recommendations to the contrary, e.g. to use the symbol $S_{hp}O_2$ for the value given by an oxymeter from Hewlett Packard [5], or that of Barker et al [2] to use the symbol Sx_{O_2} for the value given by an Oximetrix system, are unacceptable.

In conclusion we would therefore like to propose:

- that no new definitions resulting from the limitations of a method be introduced,
- that symbols and methods are not combined *per se*, and
- that definitions and symbols be disassociated from any commercial use.

SPECIAL REMARKS ON SYMBOLS AND DEFINITIONS

The special symbols concerning the parameters of the arterial oxygen status are summarized in Table I. Relevant definitions dealing with oxygen transport by arterial human blood are given in Table II.

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TABLE I. Symbols.

Term	Unit	Symbol	Specification/Comment
O_2 partial pressure	mmHg, kPa	pO_2	pAO_2 alveolar paO_2 arterial blood pcO_2 capillary blood pvO_2 venous blood $p\bar{v}O_2$ mixed venous blood $pctO_2$ skin (cutaneous) ptO_2 tissue
O_2 saturation	%*	sO_2	saO_2 arterial blood svO_2 venous blood $s\bar{v}O_2$ mixed venous blood
Partial O_2 saturation	%*	psO_2	$psaO_2$ arterial blood $psvO_2$ venous blood $ps\bar{v}O_2$ mixed venous blood
Hemoglobin concentration (Synonym: Hb content)	g/L, g/dL, mmol/L	cHb	
O_2 concentration (Synonym: O_2 content)	mL/dL, vol%, % (v/v), L/L	cO_2	caO_2 arterial blood cvO_2 venous blood $c\bar{v}O_2$ mixed venous blood
Oxy-Hb concentration (Synonym: Oxy-Hb fraction)	%*	cO_2Hb	Identical to sO_2
Carboxy-Hb concentration (Synonym: Carboxy-Hb fraction)	%*	cCOHb	
Met-Hb concentration (Synonym: Met-Hb fraction)	%*	cMetHb	
O_2 solubility (Synonym: O_2 solubility coefficient)	mL/mL/atm, mL/dL/mmHg	αO_2	
Arterio-venous O_2 difference	mmHg, %, mL/dL	$avDO_2$	The term $avDO_2$ can only be applied to a given organ, whereas $a\bar{v}DO_2$ can also refer to the whole organism.
Alveolo-arterial O_2 difference	mmHg	$AaDO_2$	
O_2 uptake	mL/min	$\dot{V}O_2$	
O_2 availability (Synonym: O_2 transport capacity; O_2 supply)	mL/min	$\dot{A}O_2$	
O_2 consumption	mL/min	$\dot{Q}O_2$	Identical to VO_2 when used in conjunction with $a\bar{v}DO_2$ under steady state conditions. Use of $avDO_2$ gives the O_2 consumption of an organ.

* can also be expressed as a fraction (without units)

TABLE II. Definitions

Terms	Definitions	Comments
O_2 partial pressure	The pressure exerted by O_2 in a mixture (e.g. CO_2, N_2, H_2O, etc.) of gases (e.g. alveolar gas, air), in a liquid (e.g. blood, cerebrospinal fluid) or in tissue.	In the case of blood the O_2 partial pressure describes the pressure of both the physically dissolved and chemically bound oxygen.
Normoxia	Normal oxygen partial pressure at a defined location and under defined conditions.	Normoxia in the arterial blood of a patient presumes knowledge of the normal value in relation to the age, sex, relative body weight and barometric pressure.
Hypoxia	Decreased O_2 partial pressure (compared to normoxia).	The term hypoxia will continue to be used generally to describe an oxygen deficit. Greater specificity in terminology is to be preferred, however (e.g. arterial hypoxia, tissue hypoxia, etc.).
Hyperoxia	Increased O_2 partial pressure (compared to normoxia).	An increase in the inhaled oxygen concentration (normobaric) and/or the total pressure in a pressure chamber (hyperbaric) employed therapeutically.
O_2 saturation	1. The concentration (content) of O_2 bound to hemoglobin in relation to the O_2 binding capacity (the theoretical maximum for Hb-bound O_2), expressed as a fraction or as a percentage: sO_2 = (cO_2 - physically dissolved O_2)/O_2 capacity.	The result of measuring the O_2 content (after deducting physically dissolved O_2) in relation to the O_2-capacity.
	2. Oxyhemoglobin as a proportion of the total hemoglobin, expressed as a fraction or as a percentage, Total Hb = O_2Hb + Hb + COHb + MetHb etc.: sO_2 = cO_2Hb/(cO_2Hb + cHb + cCOHb + cMetHb).	The result of photometric determination with equipment using 4-7 wavelengths (Oxymeter). Not recommended [5]: Oxyhemoglobin saturation (HbO_2) or fractional saturation (So_2(frac)).

(continued)

TABLE II. Definitions, continued.

Partial O_2-saturation	The concentration of oxyhemoglobin as a fraction or percentage of the sum of the concentrations of Deoxy-Hb (Hb) plus Oxy-Hb (O_2Hb) alone: $psO_2 = cO_2Hb/(cO_2Hb + cHb)$.	1. The result of photometric determination using only 2 wavelengths. 2. Obtained by calculation from the pO_2 and the O_2-binding curve under defined conditions (pH, pCO_2, temp., etc.). The term "partial" is used to emphasize that only a portion of the Hb (O_2Hb + Hb) is taken into account resulting in limited diagnostic relevance. The term "available Hb" for the sum of Hb + O_2Hb (i.e. the Hb available for O_2-transport) is unacceptable since the conditions of measurement are not defined: Depending upon the exposure time and magnitude of the pO_2 and the MetHb-reductase activitiy, COHb and MetHb are converted into "available" Hb (*in vivo* and *in vitro*). The recommendation of Payne and Severinghaus [5] to saturate with a "minimum volume of oxygen" to prevent removal of COHb and MetHb is not practicable. Not recommended [5]: *In vivo* (S_{O_2}) or functional O_2-saturation (S_{O_2}(func)), or pulse-oxymeter saturation ($Sp\hat{O}_2$).
Oxygenation	Reversible cooperative binding of oxygen to the bivalent iron of hemoglobin, whereby deoxygenated hemoglobin is converted to oxygenated hemoglobin. The splitting off of O_2 is referred to as deoxygenation.	Oxygenation must be distinguished from oxidation, in which an increase in the valency of iron takes place (hemiglobin formation from hemoglobin). The term "reduced Hb" [5] for deoxygenated hemoglobin should be avoided since iron is also present in divalent form (Fe^{++}) in the case of O_2Hb [8]. The general use of the term "oxygenation" in the sense of "oxygen enrichment" should be avoided or specified.
Hypoxygenation	Decrease in O_2-saturation at a defined location and under defined conditions.	
Hb-concentration (Hb-content)	1. Concentration of hemoglobin in blood (e.g. g/dL).	The result of the photometric determination of Hb in blood.
Total Hb-concentration (cHb)	2. Sum of all Hb-derivatives in blood (THb = total Hb): $THb = cHHb + cO_2Hb + cCOHb + cMetHb$.	The result of the spectrophotometric determination in a multi-wavelength oxymeter.
Hemoglobin derivatives:		
Hemoglobin (Hb, HHb)	Deoxy-Hb (Hb without O_2).	
Oxyhemoglobin (O_2Hb)	Oxy-Hb (Hb with bound O_2).	The term "oxidized Hb" should be eliminated.

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TABLE II. Definitions, continued.

Carboxyhemoglobin (COHb)	Hemoglobin with reversibly bound carbon monoxide (CO).	CO is bound with a high affinity but reversibly.
Methemoglobin (MetHb, Hb^+, Hi)	Hemoglobin in an oxidized state, also known as hemiglobin, that is unavailable for O_2-transport.	
Sulfhemoglobin (SHb, SulfHb)	Hemoglobin with bound sulphur (H_2S action on hemoglobin).	
Cyanohemiglobin (HiCN)	Hemiglobin with bound cyanide (HCN action on hemiglobin).	Only occurs *in vitro*.
OxyHb concentration (cO_2Hb)	Proportion of O_2Hb in blood in relation to total Hb; expressed as a fraction (without dimensions) or as a percentage (%). Identical to O_2-saturation (sO_2).	The definition by Siggaard-Andersen [6] of cO_2Hb as the "HbO_2 fraction" in relation to cHb + $cHbO_2$ (rather than to total Hb) should be rejected since the fractions of COHb, MetHb and SulfHb are related to the total Hb. The concentrations (fractions) of all Hb derivatives should be related to total Hb merely for practical reasons.
CarboxyHb concentration (cCOHb)	see cO_2Hb	
MetHb concentration (cMetHb, cHi)	see cO_2Hb	
SulfHb concentration (cSulfHb, cSHb)	see cO_2Hb	
O_2 concentration (Synonym: O_2 content)	The sum of the amounts of chemically bound and physically dissolved oxygen in blood.	
Normoxemia	The normal O_2 concentration in a blood sample under defined conditions.	
Hypoxemia	Reduced O_2 concentration compared to normoxemia.	The decrease in cO_2 is accompanied by:
Hypoxic hypoxemia	Hypoxemia as a result of hypoxia (decreased pO_2).	- decreased pO_2 and sO_2 with normal cHb.
Toxemic (toxic) hypoxemia	Hypoxemia as a result of a decrease in O_2 binding ability of Hb (e.g. by formation of COHb or MetHb)(decreased sO_2).	- decreased sO_2 with normal pO_2 and cHb.
Anemic hypoxemia	Hypoxemia as a result of anemia (decreased cHb).	- decreased cHb with normal pO_2 and sO_2.
Hyperoxemia	Increased O_2 concentration compared with normoxemia.	

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TABLE II. Definitions, continued.

O_2-solubility of the blood	Proportionality between O_2 partial pressure and the concentration of physically dissolved oxygen in blood; usually described by the O_2-solubility coefficient.	The most widespread is the Bunsen solubility coefficient (mL O_2/mL/atm).
Hüfner Number (Synonym: Hüfner factor)	The maximum amount of oxygen that can be bound by 1 g of hemoglobin.	On the basis of a molecular weight of 64458 and the fact that 1 mol Hb can bind a maximum of 4 mol O_2, the theoretical value is 1.39 mL O_2/g Hb. The fact that in practically all individuals about 3 % of the total Hb exits as COHb, MetHb or SHb should not be expressed as an "*in vivo* Hüfner number", but as an appropriate reduction in the O_2-saturation of the blood (sO_2 = 97 %).
O_2 capacity	The maximum amount of oxygen that can be bound by Hb in a defined blood volume; expressed as O_2 concentration (e.g. mL O_2/dL). The O_2 capacity is the product of cHb and the Hüfner number.	The O_2 capacity is essentially a theoretical value since no experimental method is available that allows complete saturation of the total Hb with O_2. Traces of COHb and MetHb will always remain which, although not interfering with the determination of the O_2 capacity, will be included in the measurement of Hb (as total Hb). Not to be confused with the "O_2 transport capacity" (see definition).
O_2 binding curve (Synonym: O_2 dissociation curve)	Graphical relationship (S-shaped) between the O_2-saturation of hemoglobin (chemically bound O_2) and the O_2 partial pressure of the blood: sO_2(%) as a function of pO_2(mmHg), or as psO_2(%) as a function of pO_2(mmHg).	At a pO_2 of over 150 mmHg, a maximum sO_2 can be reached of only up to 98 %, a psO_2 of 100 %, resp.
O_2 content curve (Synonym: O_2 concentration curve)	Graphical relationship (S-shaped) between the O_2 content (chemically bound plus physically dissolved O_2) and O_2 partial pressure of the blood: cO_2 (mL/dL) as a function of pO_2 (mmHg).	At a pO_2 of over 150 mmHg, the O_2 content curve shows a linear increase whose slope is dependent upon the O_2-solubility.
Half-saturation pressure (p50, p0.5)	The O_2 partial pressure that leads to 50 % saturation of hemoglobin (sO_2 = 50 % or 0.5).	The p50 (p0.5) provides an approximate indicator of the status of the O_2 binding curve in the form of sO_2 (%) as a function of pO_2 (mmHg) or, in the presence of significant concentrations of COHb or MetHb, as psO_2 (%) as a function of pO_2 (mmHg).
Arterio-venous O_2-difference	The difference between arterial and venous ($avDO_2$) or mixed venous ($\bar{a}\bar{v}DO_2$) oxygen, expressed in units of partial pressure (pO_2), saturation (sO_2) or concentration (cO_2) (mmHg, %, mL/dL).	The greatest predictive value is provided by the $avDO_2$ in concentration units; this is the only parameter that yields information on the O_2 consumption of an organism or organ (taking into account the blood flow).

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TABLE II. Definitions, continued.

Alveolo-arterial O_2-difference	The difference between the alveolar and arterial O_2 partial pressures.	
O_2 uptake	The amount of O_2 taken up per unit time via the respiration (mL O_2/min), given by the product of the ventilation and the difference between the concentrations of inhaled and exhaled O_2: $VO_2 = V \cdot (FIO_2 - FEO_2)$.	Under steady state conditions identical to the O_2 consumption of the organism.
O_2 availability (Synonyms: O_2 transport capacity; O_2 supply)	The amount of oxygen supplied to the organism via the blood flow per unit time (mL O_2/min), given by the product of the cardiac output and the arterial O_2 concentration: $AO_2 = C.O. \cdot caO_2$.	
O_2 consumption	The amount of oxygen consumed by the whole organism per unit time (mL O_2/min), given by the product of the cardiac output and the arterio-mixed venous O_2 difference: $QO_2 = C.O. \cdot a\bar{v}DO_2$.	Under steady state conditions identical to the O_2 uptake.