Órgãos respiratórios em Metazoa

Sem estruturas respiratórias = Respiração "cutânea"

Porífera, Ctenofora, Cnidária, Gastrotricha, Nematoda, Platyhelminthes, Nemertini, Sipunculida, Echiurida, Annelida, Phoronida, Brachiopoda, Hemichordata, Echinodermata, Craniota

Branquias

Priapulida, Mollusca, Annelida, Euarthropoda, Echinodermata, Craniota

Pulmão

Mollusca, Euarthropoda, Echinodermata, Craniota

Sistema traqueal

Onychophora, Euarthropoda

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Porífera, Ctenofora, Cnidária, Gastrotricha, Nematoda, Platyhelminthes, Nemertini, Sipunculida, Echiurida, Annelida, Phoronida, Brachiopoda, Hemichordata, Echinodermata, Craniota

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Priapulida, Mollusca, Annelida, Euarthropoda, Echinodermata, Craniota

Pulmão

Mollusca, Euarthropoda, Echinodermata*, Craniota

* Arvore respiratória em Holothuria

Sistema traqueal

Onychophora, Euarthropoda

Pigmentos respiratórios em Metazoa

Hemoglobina

Gastrotricha, Nematoda, Platyhelminthes, Nemertini, Mollusca, Echiurida, Annelida, Euarthropoda, Phoronida, Echinodermata, Craniota

Hemocianina

Mollusca, Onychophora, Euarthropoda

Hemeritrina

Priapulida, Sipunculida, Annelida, Brachiopoda

Pigmentos respiratórios em Metazoa

Hemoglobina

Gastrotricha, Nematoda, Platyhelminthes, Nemertini, Mo
Echiurida, Annelida, Euarthropoda, Phoronida, Echinodermata, Craniota

Hemocianina

Mollusca, Onychophora, Euarthropoda

Hemeritrina

Priapulida, Sipunculida, Annelida, Brachiopoda

Clorocruorina

Presente em alguns livros/textos mais antigos como outro tipo de pigmento respiratório; hoje considerada uma variação da hemoglobina

Conclusões: evolução de estruturas respiratórias

Comparação difícil entre grandes grupos.

Dentro de cada taxon ocorreram adaptações do sistema respiratório causadas pelo tamanho corpóreo ou por mudanças ambientais, tais como por exemplo a conquista da vida em ambiente terrestre (ocorrida em Mollusca, Arthropoda, e Craniota).

Schmidt-Rhaesa, 2007

Transporte de Oxigênio de Dióxido de Carbono pelos Líquidos Corporais

▪Sangue:

 ▪ 0,3ml de O_2 / 100ml = 0,3 vol% O_2 (solução física)

 ▪ ≈ 20 vol% O_2 conteúdo total

⇓ ⇓

Pigmentos respiratórios

• Complexos de proteína com íons metálicos e com cor característica

• Peixe de gelo (Antártica): sem hemoglobina

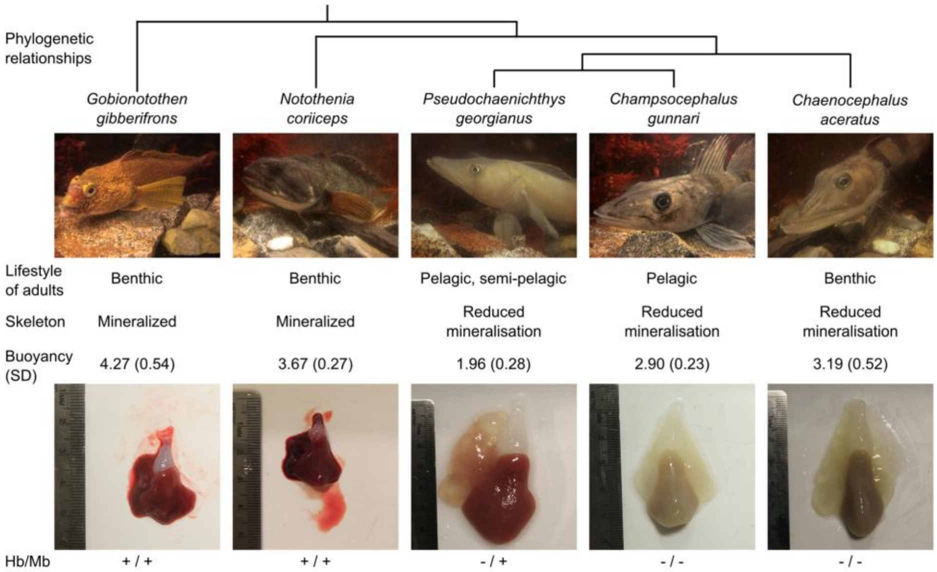
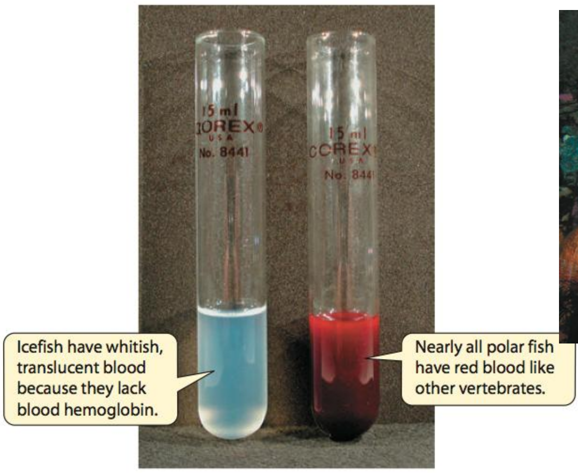


Figure 4. Diversity of ecological and physiological features in notothenioids. Phylogenetic relationships and the buoyancy data are from Near et al. (2012a) and information on adult lifestyles is reviewed in Rutschmann et al. (2011). A dissected heart is shown for each species and presence (+) and absence (−) of hemoglobin and myoglobin (Hb/Mb) is indicated as well.

Braasch et al., 2015

Peixe de gelo (Antártica)

Animais relativamente grandes sem hemoglogina e consequentemente sem transporte de O_2 ligado à hemoglobina



Peixe de gelo (Antártica)

Sem hemoglobina, como o O_2 está sendo transportado?

- Lei de Henry:
$[O_2] = Po_2 \times \alpha O_2$

Temperatura das águas ao redor da Antárcta: -2°C o ano todo

Capacidade de sangue de transportar O_2 nos peixes de gelo:
~1.0 mL O_2/100 mL

Nos peixes polares com hemoglobina: 6–7 mL O_2/100 mL

Circulação sanguínea mais rápida e maior volume de sangue nos peixes de gelo.

Evolução dos pigmentos respiratórios

Três tipos de pigmentos respiratórios ocorrem nos animais: **hemoglobina, hemeritrina e hemocianina.**

Diferenças estruturais e sem indícios que eles têm uma proteína ancestral comum.

Pigmentos respiratórios evoluídos pelo menos três vezes independentemente.

Schmidt-Rhaesa, 2007

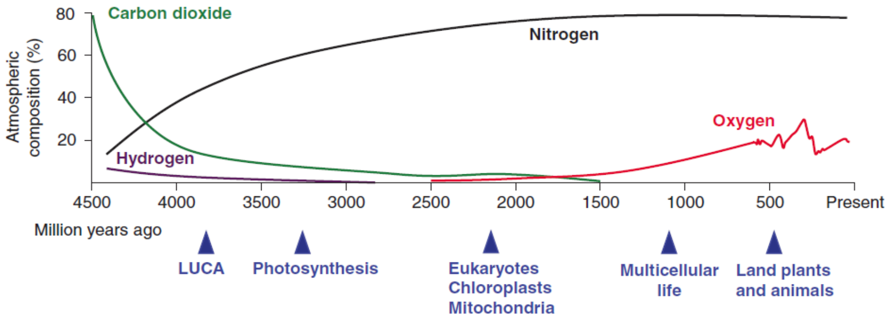


Figure 4 A general model of early evolution and atmospheric O_2 concentration. Last Universal Common Ancestor (LUCA) was anaerobic and unicellular, but possessed heme proteins and their equivalents for antioxidation and reactive O_2 species-mediated cell signaling and possibly ATP production. Photosynthesis by cyanobacteria led to O_2 accumulation, which was initially stored in rocks and sediments but later enriched the atmosphere. Eukaryotic plant and animal cells evolved that can more efficiently produce and utilize O_2, leading to multicellular organisms of increasing complexity. Around 500 Ma, atmospheric O_2 level reached the contemporary range, coinciding with an explosive appearance of terrestrial plants and animals.

Hsia et al. 2013

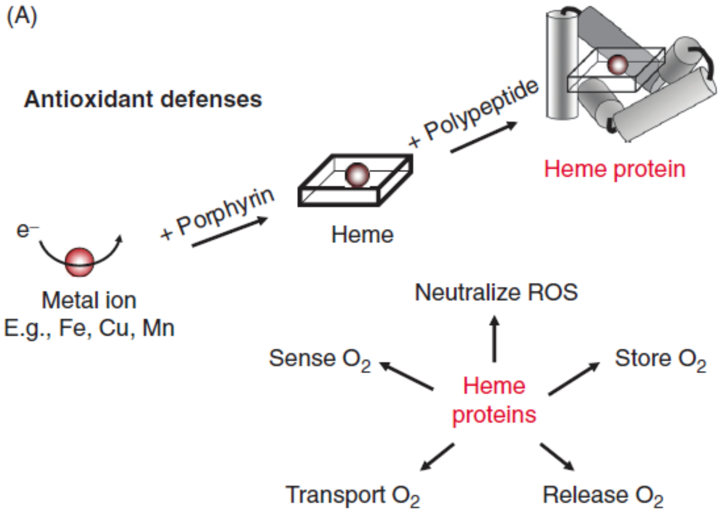
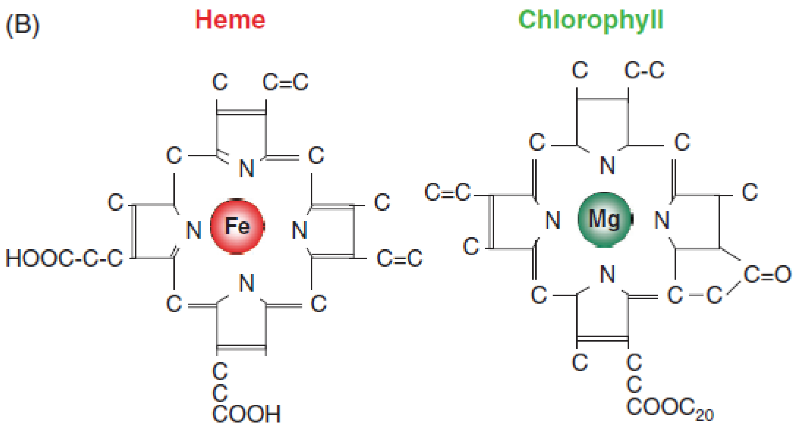


Figure 2 (A) Transitional metals ions functioned as signaling and antioxidant molecules in the earliest organisms. A molecular cage, for example, prophyrin ring, trapped these metal ions, for example, forming a heme molecule. Adding various polypeptides modulated the action of heme, resulting in heme proteins. By exaptation heme proteins participated in the neutralization of reactive O_2 species as well as the sensing, storage, transport, and release of O_2. (B) Structure of heme (containing iron) is remarkably similar to that of chlorophyll (containing magnesium).

Hsia et al. 2013



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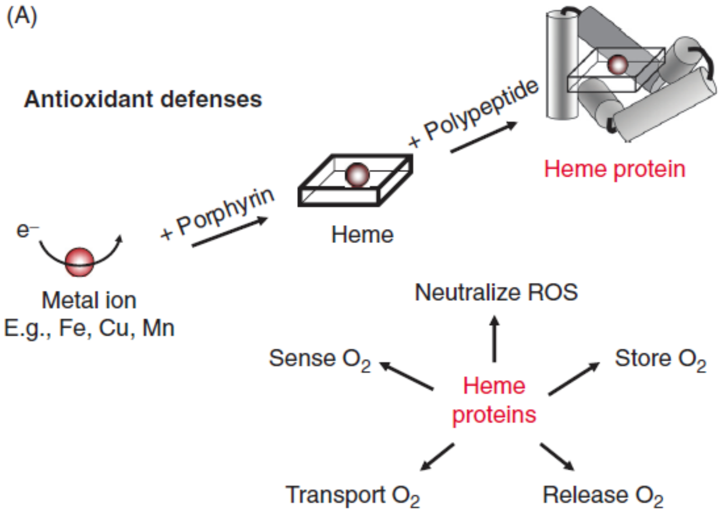

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Hsia et al. 2013

PROCEEDINGS B

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How oxygen gave rise to eukaryotic sex

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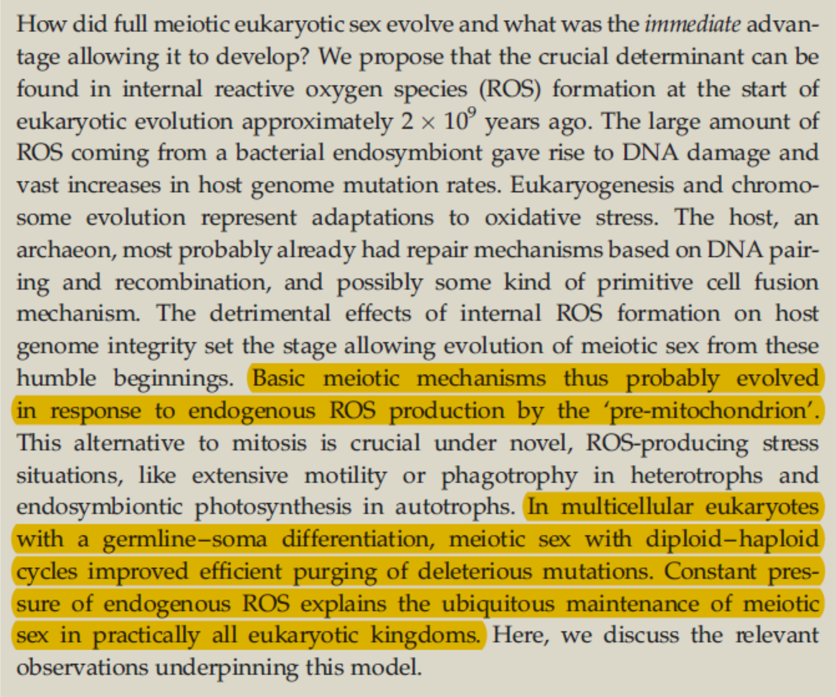
[2]Department of Medical Biochemistry, Academic Medical Centre (AMC), University of Amsterdam, Amsterdam, The Netherlands



How did full meiotic eukaryotic sex evolve and what was the *immediate* advantage allowing it to develop? We propose that the crucial determinant can be found in internal reactive oxygen species (ROS) formation at the start of eukaryotic evolution approximately 2×10^9 years ago. The large amount of ROS coming from a bacterial endosymbiont gave rise to DNA damage and vast increases in host genome mutation rates. Eukaryogenesis and chromosome evolution represent adaptations to oxidative stress. The host, an archaeon, most probably already had repair mechanisms based on DNA pairing and recombination, and possibly some kind of primitive cell fusion mechanism. The detrimental effects of internal ROS formation on host genome integrity set the stage allowing evolution of meiotic sex from these humble beginnings. Basic meiotic mechanisms thus probably evolved in response to endogenous ROS production by the 'pre-mitochondrion'. This alternative to mitosis is crucial under novel, ROS-producing stress situations, like extensive motility or phagotrophy in heterotrophs and endosymbiontic photosynthesis in autotrophs. In multicellular eukaryotes with a germline–soma differentiation, meiotic sex with diploid–haploid cycles improved efficient purging of deleterious mutations. Constant pressure of endogenous ROS explains the ubiquitous maintenance of meiotic sex in practically all eukaryotic kingdoms. Here, we discuss the relevant observations underpinning this model.

Hemoglobina = Heme + Globina

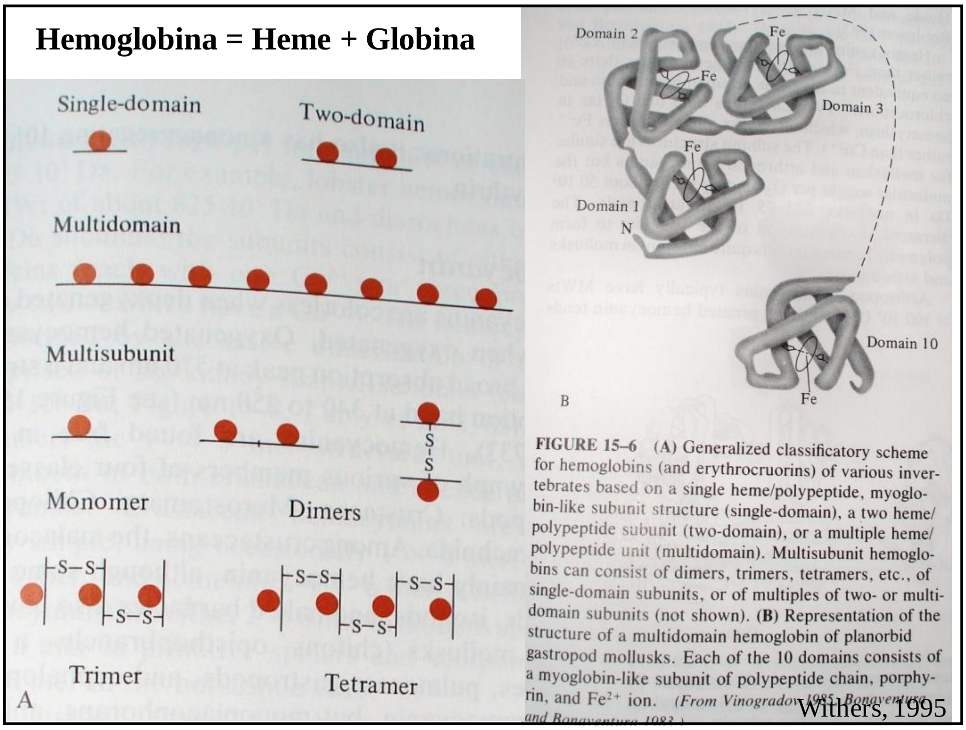


FIGURE 15–6 (**A**) Generalized classificatory scheme for hemoglobins (and erythrocruorins) of various invertebrates based on a single heme/polypeptide, myoglobin-like subunit structure (single-domain), a two heme/polypeptide subunit (two-domain), or a multiple heme/polypeptide unit (multidomain). Multisubunit hemoglobins can consist of dimers, trimers, tetramers, etc., of single-domain subunits, or of multiples of two- or multidomain subunits (not shown). (**B**) Representation of the structure of a multidomain hemoglobin of planorbid gastropod mollusks. Each of the 10 domains consists of a myoglobin-like subunit of polypeptide chain, porphyrin, and Fe^{2+} ion. *(From Vinogradov 1985; Bonaventura and Bonaventura 1983.)*

Withers, 1995

Hemoglobina = Heme + Globina

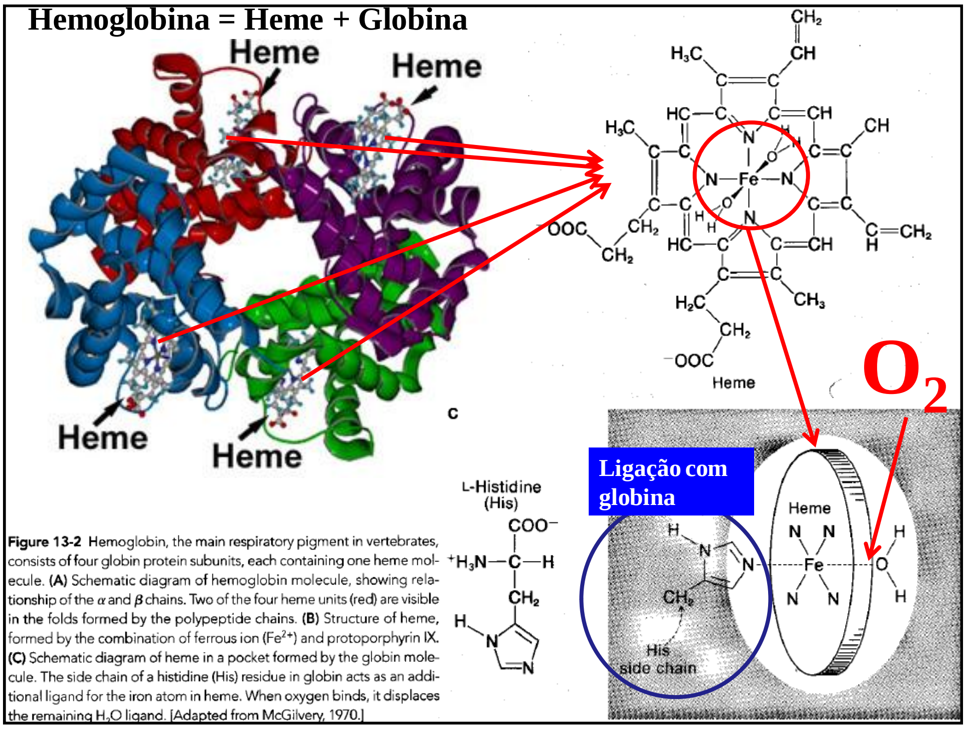


Figure 13-2 Hemoglobin, the main respiratory pigment in vertebrates, consists of four globin protein subunits, each containing one heme molecule. (**A**) Schematic diagram of hemoglobin molecule, showing relationship of the α and β chains. Two of the four heme units (red) are visible in the folds formed by the polypeptide chains. (**B**) Structure of heme, formed by the combination of ferrous ion (Fe^{2+}) and protoporphyrin IX. (**C**) Schematic diagram of heme in a pocket formed by the globin molecule. The side chain of a histidine (His) residue in globin acts as an additional ligand for the iron atom in heme. When oxygen binds, it displaces the remaining H_2O ligand. [Adapted from McGilvery, 1970.]

- Hemoglobina:
  - peso molecular: 68.000 (vertebrados, exceto ciclostomados)
  - 4 grupos prostéticos (HEME) associados com globina
  - dois dímeros ($\alpha_1\beta_1$ e $\alpha_2\beta_2$)
  - Mioglobina = uma subunidade da hemoglobina
  - oxigenação promove mudança conformacional na molécula
  - ferro no estado ferroso (Fe^{2+}) ligado a um anel de porfirina do heme
  - O_2 ligado à molécula → oxihemoglobina
  - O_2 **não** ligado à molécula → desoxihemoglobina
  - Fe^{2+} transformado (oxidação) em Fe^{3+} → methemoglobina
  - CO ligado à molécula → carboxyhemoglobina

Hemoglobina e proteínas relacionadas

- Existem diversas moléculas envolvidas na transferência de elétrons ou O_2 e que incluem um anel de porfirina com Fe^{2+}.
- Hemoglobinas adaptarem-se para reversivelmente ligar-se ao O_2.
- São encontradas em bactérias, fungos, plantas e animais (plesiomorfia dos metazoa).
- Muito variável em tamanho e localização nos animais (músculo, sistema nervoso, sangue, extracelular, etc.).
- Muitas vezes mais de um tipo de hemoglobina presente num animal.
- Expressão de hemoglobina bastante flexível, acontecendo quando e aonde for necessário.
- Proteínas relacionadas:
  - Craniota: mioglobina, citoglobina, neuroglobina (cérebro).
  - auxiliam no suprimento de O_2 para células de tecidos específicos.

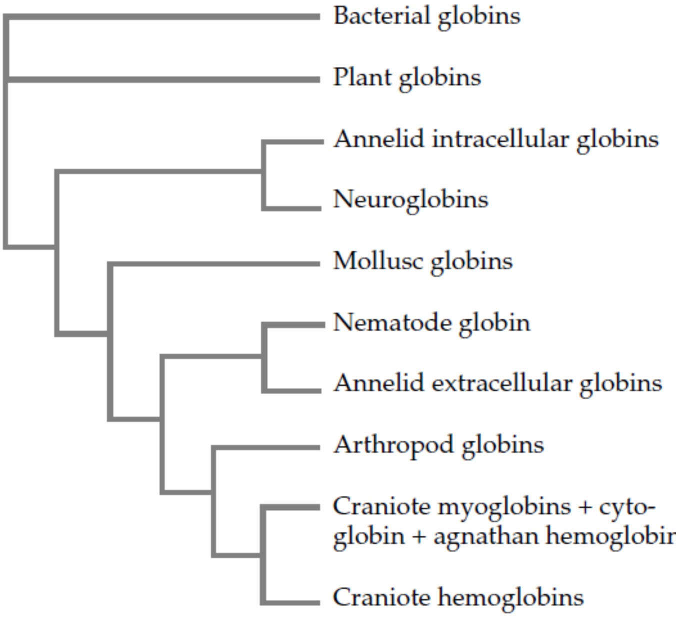
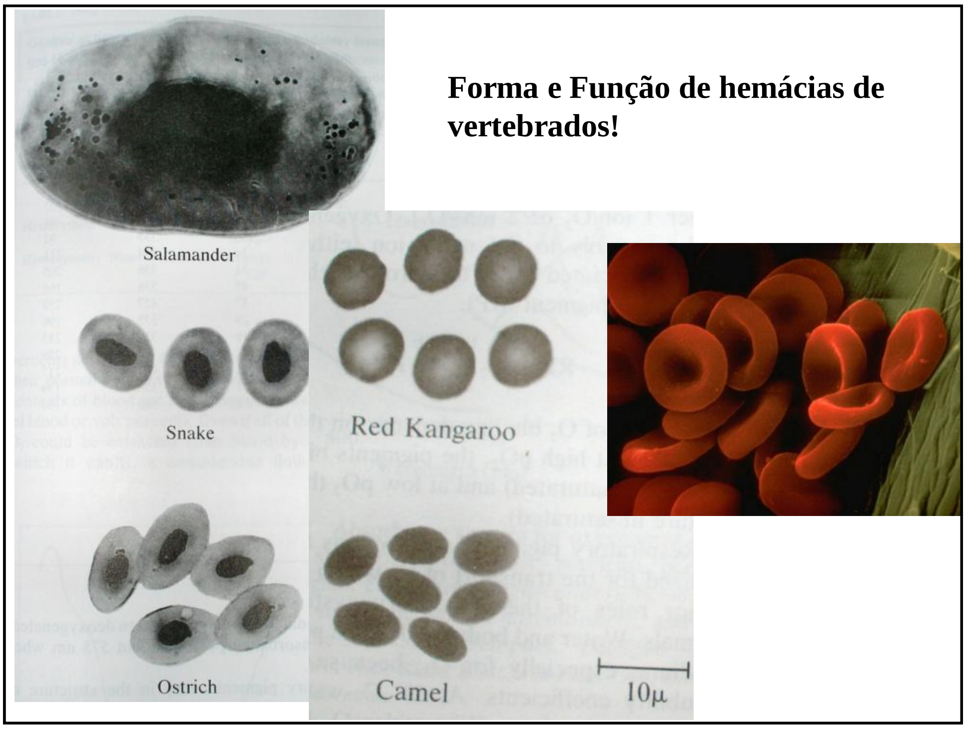


Fig. 11.13. Evolution of the globin superfamily, after Burmester et al. (2000).

Schmidt-Rhaesa, 2007

Forma e Função de hemácias de vertebrados!



Hemeritrina

- Proteína com ferro mas sem grupo Heme.
- Presente em 4 taxa: Priapulida, Sipunculida, Brachiopoda, gênero *Magelona (*Polychaeta, Annelida*)*
- Hemeritrina plesiomórfica de Bilatéria (no caso de Brachiopoda serem relacionados aos Deuterostomia) ou plesiomórfica dos Protostomia (no caso de Brachiopoda serem Spiralia).
- Domínio parecido com Hemeritrina encontrado na bactéria *Desulphovibrio vulgaris.*

Schmidt-Rhaesa, 2007

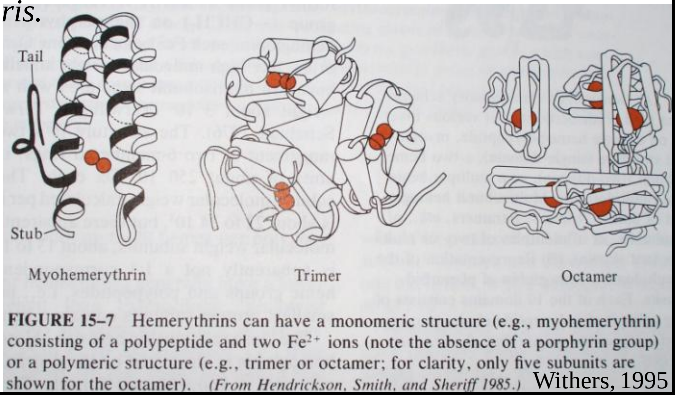


FIGURE 15–7 Hemerythrins can have a monomeric structure (e.g., myohemerythrin) consisting of a polypeptide and two Fe^{2+} ions (note the absence of a porphyrin group) or a polymeric structure (e.g., trimer or octamer; for clarity, only five subunits are shown for the octamer). *(From Hendrickson, Smith, and Sheriff 1985.)*

Withers, 1995

A superfamília das hemocianinas

- Hemocianina e proteínas relacionadas são moléculas muito grandes com cobre para ligação do O_2.
- Outras proteínas:
  - Fenoloxidases de artrópodes
  - Pseudohemocianinas de crustáceos
  - Hexamerinas de armazenamento de insetos
  - Tirosinases de moluscos
- Hemocianinas ocorrem como pigmentos respiratórios em moluscos e artrópodes (Chelicerata, Crustacea, Diplopoda, Insecta)
- Grandes diferenças entre as moléculas de hemocianina → possivelmente evolução independente nos diversos grupos a partir de fenoloxidase (= moléculas consumidores de O_2 no metabolismo de melanina → esclerotização do exoesqueleto).
- Fenoloxidases conservaram função ancestral e hemocianina (derivados da mesma proteína ancestral) adquiriram outra função.

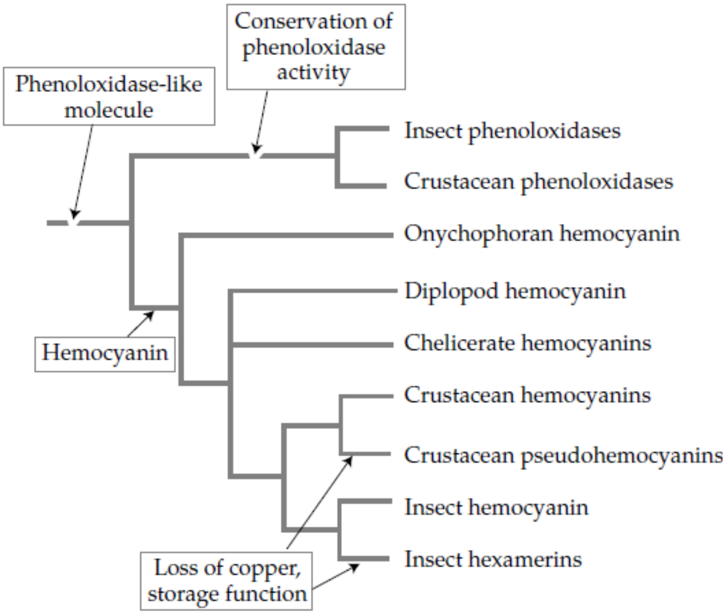


Fig. 11.14. Evolution of the hemocyanin protein superfamily in arthropods, after Burmester (2001, 2002).

Schmidt-Rhaesa, 2007

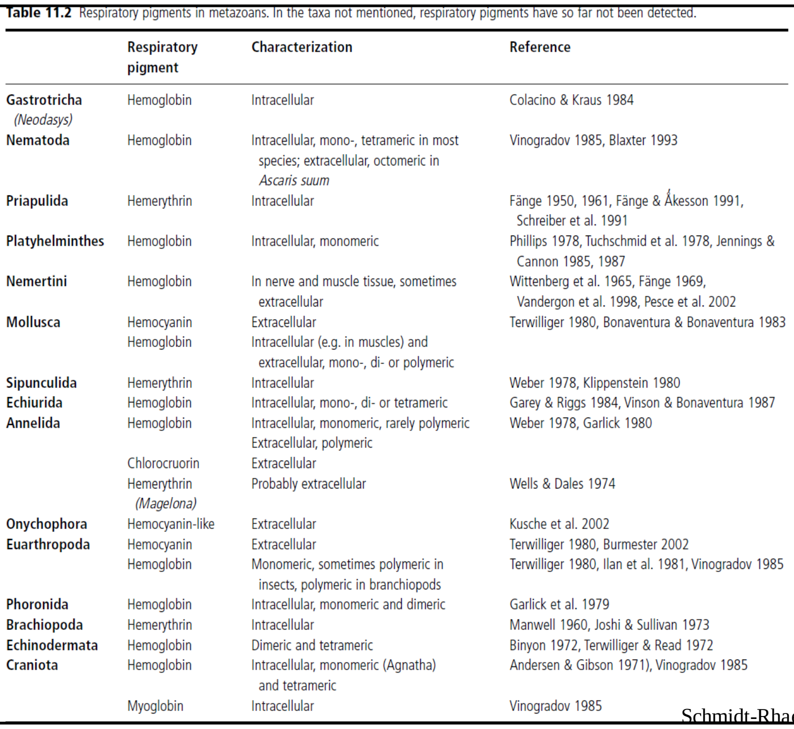
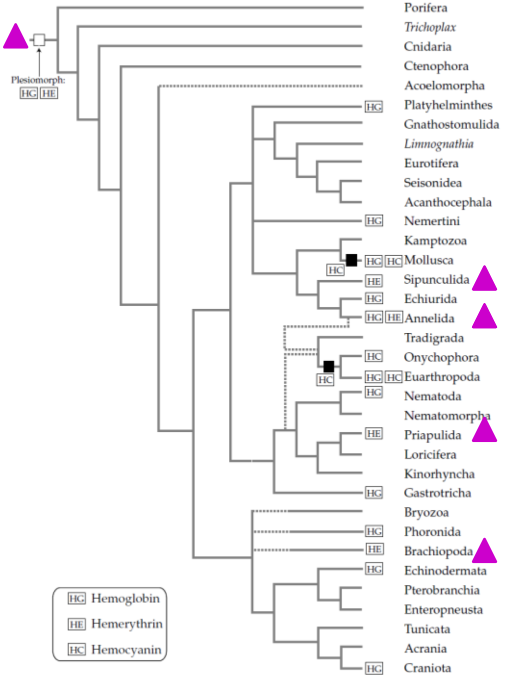


Table 11.2 Respiratory pigments in metazoans. In the taxa not mentioned, respiratory pigments have so far not been detected.

	Respiratory pigment	Characterization	Reference
Gastrotricha *(Neodasys)*	Hemoglobin	Intracellular	Colacino & Kraus 1984
Nematoda	Hemoglobin	Intracellular, mono-, tetrameric in most species; extracellular, octomeric in *Ascaris suum*	Vinogradov 1985, Blaxter 1993
Priapulida	Hemerythrin	Intracellular	Fänge 1950, 1961, Fänge & Åkesson 1991, Schreiber et al. 1991
Platyhelminthes	Hemoglobin	Intracellular, monomeric	Phillips 1978, Tuchschmid et al. 1978, Jennings & Cannon 1985, 1987
Nemertini	Hemoglobin	In nerve and muscle tissue, sometimes extracellular	Wittenberg et al. 1965, Fänge 1969, Vandergon et al. 1998, Pesce et al. 2002
Mollusca	Hemocyanin	Extracellular	Terwilliger 1980, Bonaventura & Bonaventura 1983
	Hemoglobin	Intracellular (e.g. in muscles) and extracellular, mono-, di- or polymeric	
Sipunculida	Hemerythrin	Intracellular	Weber 1978, Klippenstein 1980
Echiurida	Hemoglobin	Intracellular, mono-, di- or tetrameric	Garey & Riggs 1984, Vinson & Bonaventura 1987
Annelida	Hemoglobin	Intracellular, monomeric, rarely polymeric Extracellular, polymeric	Weber 1978, Garlick 1980
	Chlorocruorin	Extracellular	
	Hemerythrin *(Magelona)*	Probably extracellular	Wells & Dales 1974
Onychophora	Hemocyanin-like	Extracellular	Kusche et al. 2002
Euarthropoda	Hemocyanin	Extracellular	Terwilliger 1980, Burmester 2002
	Hemoglobin	Monomeric, sometimes polymeric in insects, polymeric in branchiopods	Terwilliger 1980, Ilan et al. 1981, Vinogradov 1985
Phoronida	Hemoglobin	Intracellular, monomeric and dimeric	Garlick et al. 1979
Brachiopoda	Hemerythrin	Intracellular	Manwell 1960, Joshi & Sullivan 1973
Echinodermata	Hemoglobin	Dimeric and tetrameric	Binyon 1972, Terwilliger & Read 1972
Craniota	Hemoglobin	Intracellular, monomeric (Agnatha) and tetrameric	Andersen & Gibson 1971), Vinogradov 1985
	Myoglobin	Intracellular	Vinogradov 1985

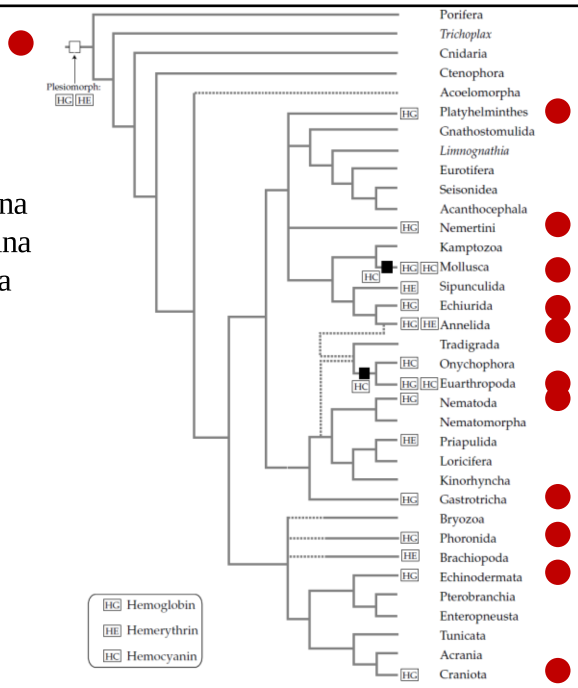
Schmidt-Rhaesa, 2007



🟦 Hemocianina
● Hemoglobina
▲ Hemeritrina

Fig. 11.12. Distribution of hemoglobin, hemerythrin, and hemocyanin on the metazoan tree. Because hemoglobin- and hemerythrin-related molecules occur outside metazoans, they are assumed to be plesiomorphic.

Schmidt-Rhaesa, 2007



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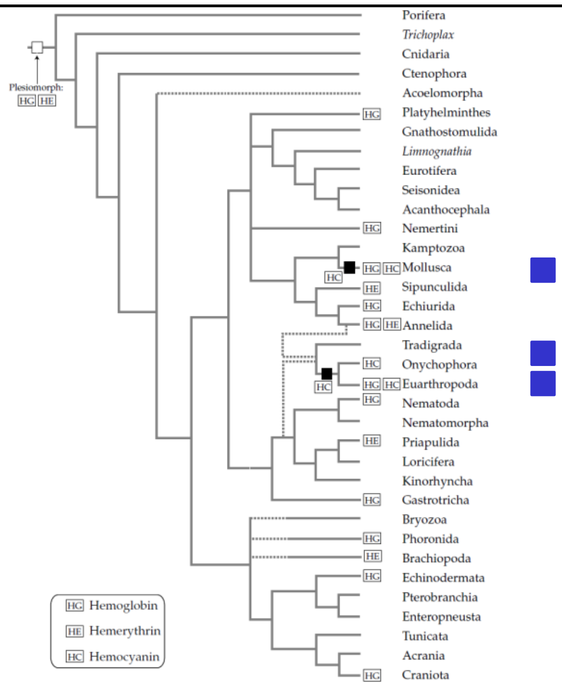

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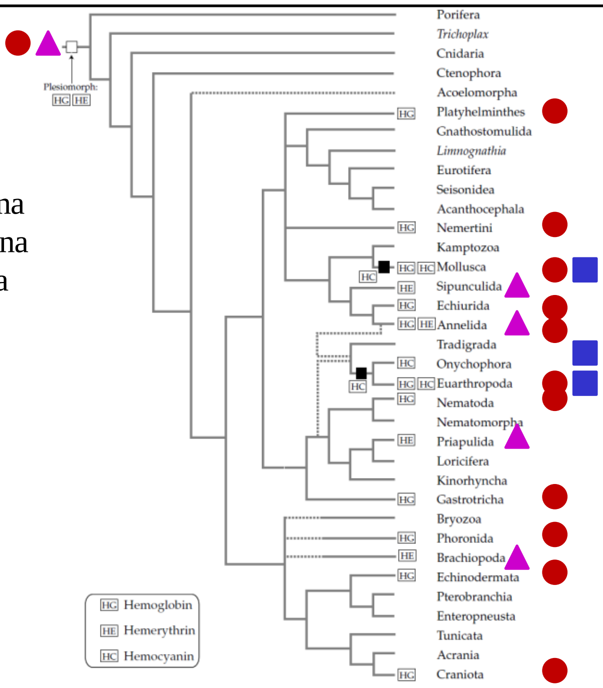

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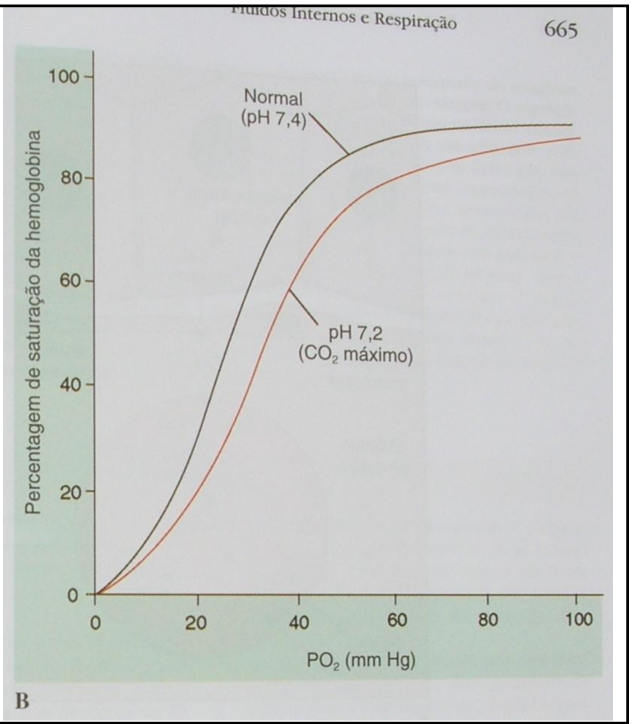
  - CO ligado à molécula → carboxyhemoglobina

Pigmentos respiratórios

- Curvas de saturação/dissociação



Mixing technique for study of oxygen-hemoglobin equilibrium: a critical evaluation

J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 45(5): 818–822, 1978.

PETER SCHEID AND MICHAEL MEYER

Sangue sem O_2#

1,0 ml

0,0 ml

Sangue com 100% O_2*

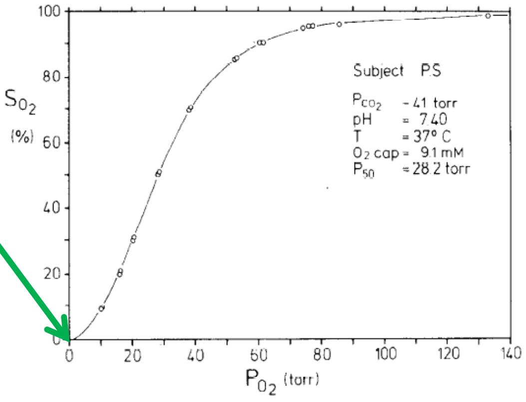


FIG. 2. Standard O_2 dissociation curve of a healthy, male nonsmoker. Values measured at constant P_{CO_2} and corrected to pH = 7.40. Continuous curve calculated from average data collected by Severinghaus (13) according to algorithm of Thomas (14), and adjusted to the actual P_{50}.

Borbulhamento de 100% N_2 na amostra de sangue
* Borbulhamento de 100% O_2 na amostra de sangue

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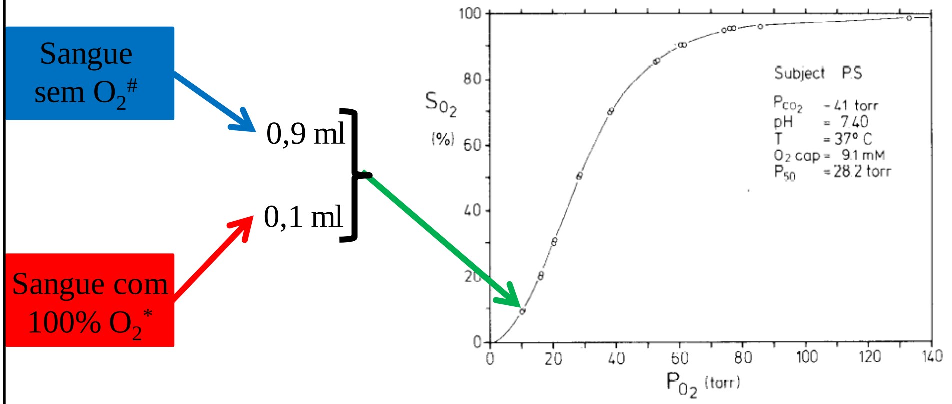

Sangue sem O_2#

0,9 ml

0,1 ml

Sangue com 100% O_2*

FIG. 2. Standard O_2 dissociation curve of a healthy, male non-smoker. Values measured at constant P_{CO_2} and corrected to pH = 7.40. Continuous curve calculated from average data collected by Severinghaus (13) according to algorithm of Thomas (14), and adjusted to the actual P_{50}.

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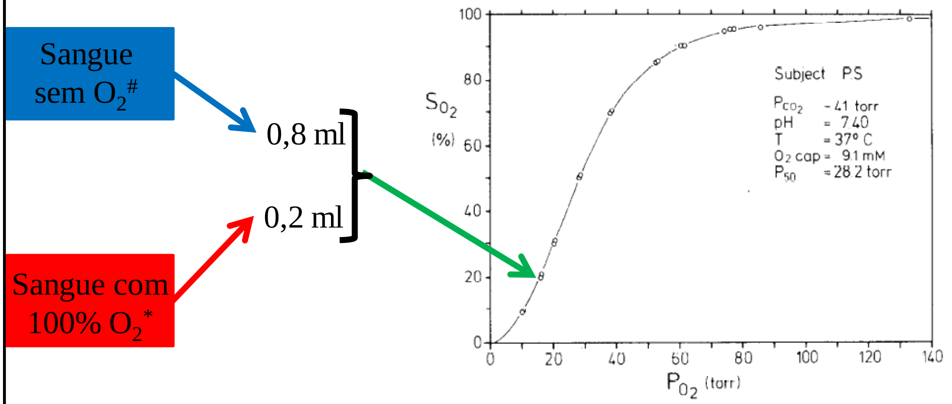

Sangue sem O_2#

0,8 ml

0,2 ml

Sangue com 100% O_2*

FIG. 2. Standard O_2 dissociation curve of a healthy, male non-smoker. Values measured at constant P_{CO_2} and corrected to pH = 7.40. Continuous curve calculated from average data collected by Severinghaus (13) according to algorithm of Thomas (14), and adjusted to the actual P_{50}.

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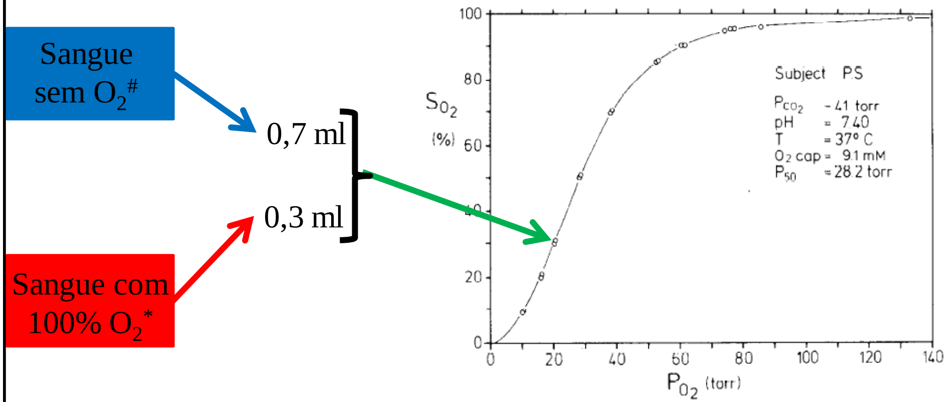


Sangue sem O_2#

0,7 ml

0,3 ml

Sangue com 100% O_2*

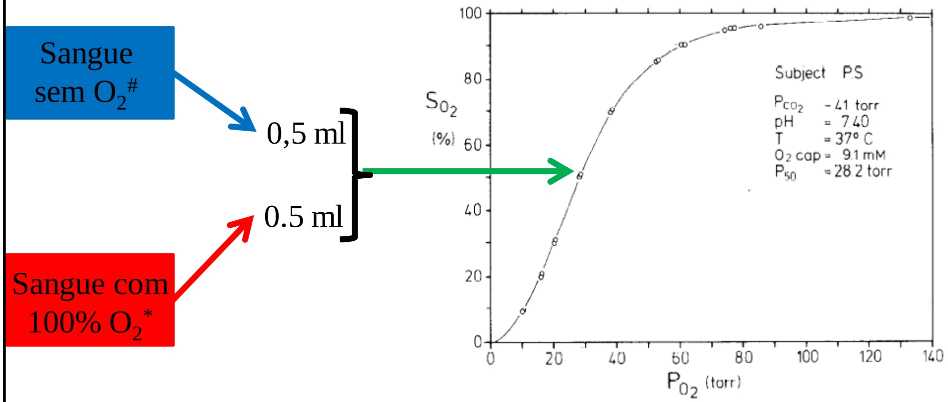
FIG. 2. Standard O_2 dissociation curve of a healthy, male nonsmoker. Values measured at constant P_{CO_2} and corrected to pH = 7.40. Continuous curve calculated from average data collected by Severinghaus (13) according to algorithm of Thomas (14), and adjusted to the actual P_{50}.

\# Borbulhamento de 100% N_2 na amostra de sangue
* Borbulhamento de 100% O_2 na amostra de sangue

Mixing technique for study of oxygen-hemoglobin equilibrium: a critical evaluation

J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 45(5): 818–822, 1978.

PETER SCHEID AND MICHAEL MEYER



Sangue sem O_2#

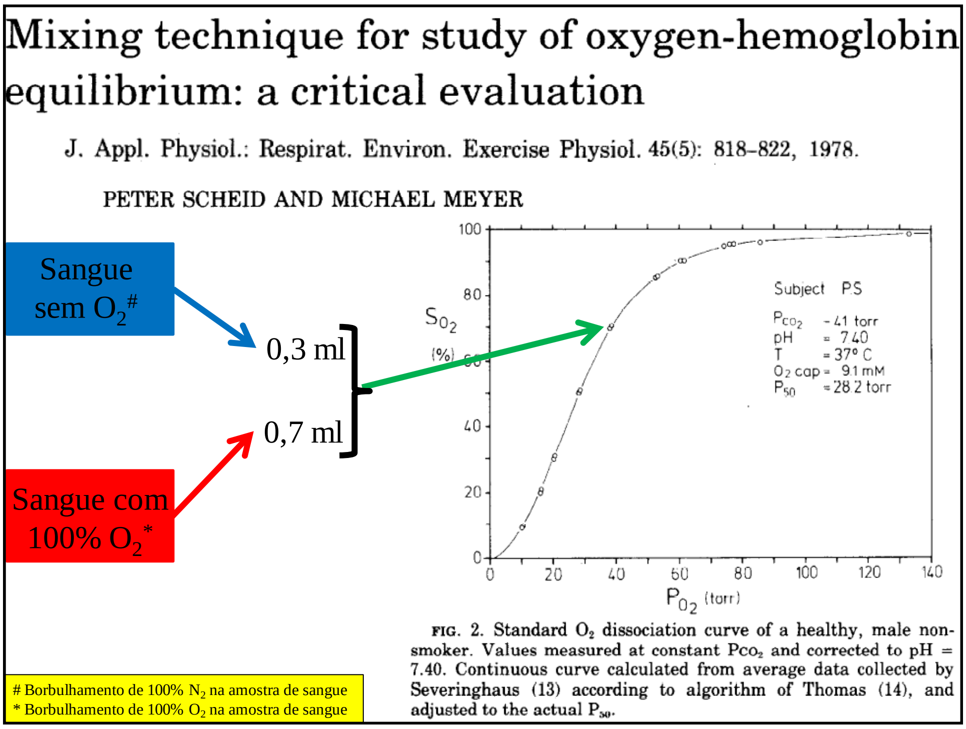
0,5 ml

0.5 ml

Sangue com 100% O_2*

FIG. 2. Standard O_2 dissociation curve of a healthy, male nonsmoker. Values measured at constant P_{CO_2} and corrected to pH = 7.40. Continuous curve calculated from average data collected by Severinghaus (13) according to algorithm of Thomas (14), and adjusted to the actual P_{50}.

\# Borbulhamento de 100% N_2 na amostra de sangue
* Borbulhamento de 100% O_2 na amostra de sangue



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Sangue sem O_2#

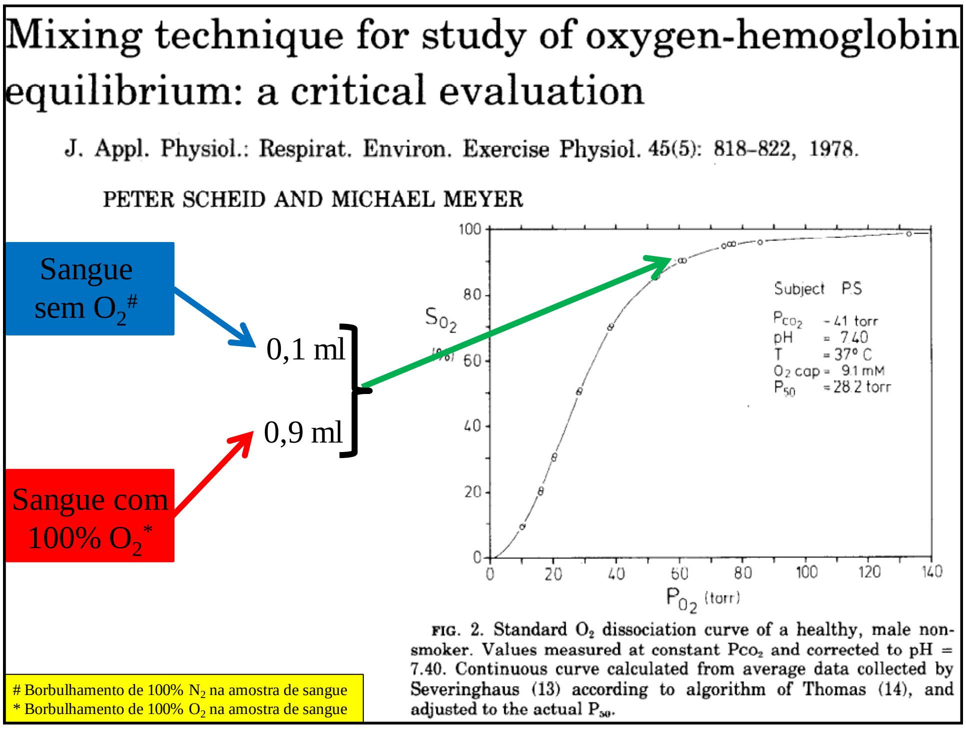
Sangue com 100% O_2*

0,3 ml

0,7 ml

FIG. 2. Standard O_2 dissociation curve of a healthy, male nonsmoker. Values measured at constant P_{CO_2} and corrected to pH = 7.40. Continuous curve calculated from average data collected by Severinghaus (13) according to algorithm of Thomas (14), and adjusted to the actual P_{50}.

Borbulhamento de 100% N_2 na amostra de sangue
* Borbulhamento de 100% O_2 na amostra de sangue



Mixing technique for study of oxygen-hemoglobin equilibrium: a critical evaluation

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Sangue sem O_2#

Sangue com 100% O_2*

0,1 ml

0,9 ml

FIG. 2. Standard O_2 dissociation curve of a healthy, male nonsmoker. Values measured at constant P_{CO_2} and corrected to pH = 7.40. Continuous curve calculated from average data collected by Severinghaus (13) according to algorithm of Thomas (14), and adjusted to the actual P_{50}.

Borbulhamento de 100% N_2 na amostra de sangue
* Borbulhamento de 100% O_2 na amostra de sangue

Mixing technique for study of oxygen-hemoglobin equilibrium: a critical evaluation

J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 45(5): 818–822, 1978.

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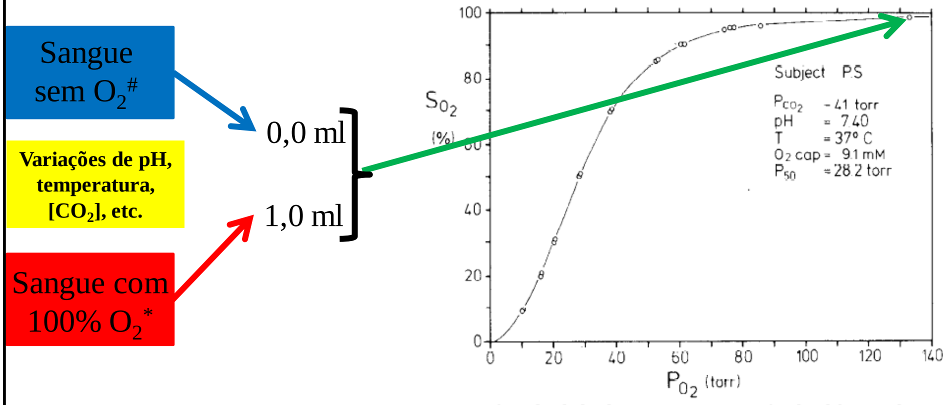
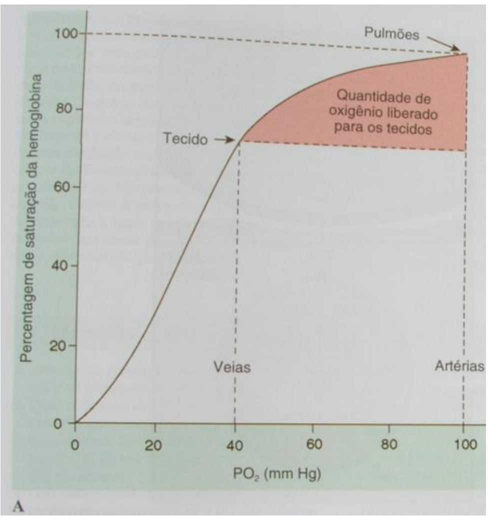


FIG. 2. Standard O_2 dissociation curve of a healthy, male nonsmoker. Values measured at constant P_{CO_2} and corrected to pH = 7.40. Continuous curve calculated from average data collected by Severinghaus (13) according to algorithm of Thomas (14), and adjusted to the actual P_{50}.

\# Borbulhamento de 100% N_2 na amostra de sangue
* Borbulhamento de 100% O_2 na amostra de sangue

Pigmentos respiratórios:

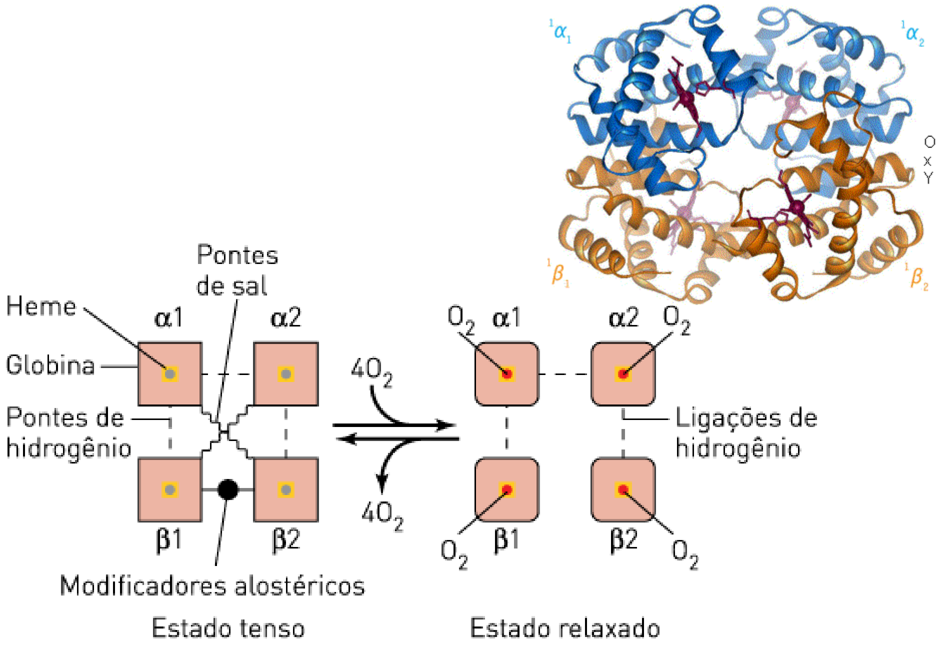
- **Curvas de saturação/dissociação da hemoglobina**



Transporte de O_2 no sangue:

- 1 molécula de Hb pode se combinar a 4 moléculas de O_2
- Pressão parcial (PO_2) → determina extensão da ligação de O_2
- Um mmol de heme pode ligar-se a um mmol de O_2 que representa um volume de 22,4ml de O_2

➔ sangue com 0,9mmol Hb/100ml de sangue → 20,2 vol% O_2



(b) Um modelo para a cooperatividade da hemoglobina

Moyes, Schultz, 2010

Percentagem de saturação

- Curvas de dissociação de Hemoglobina
  - estado tenso (T)
  - estado relaxado (R)

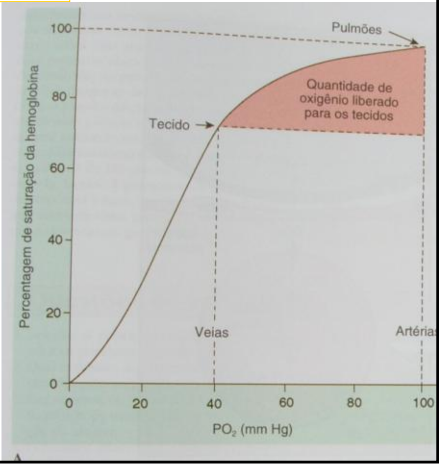
Cooperatividade das subunidades

⇓

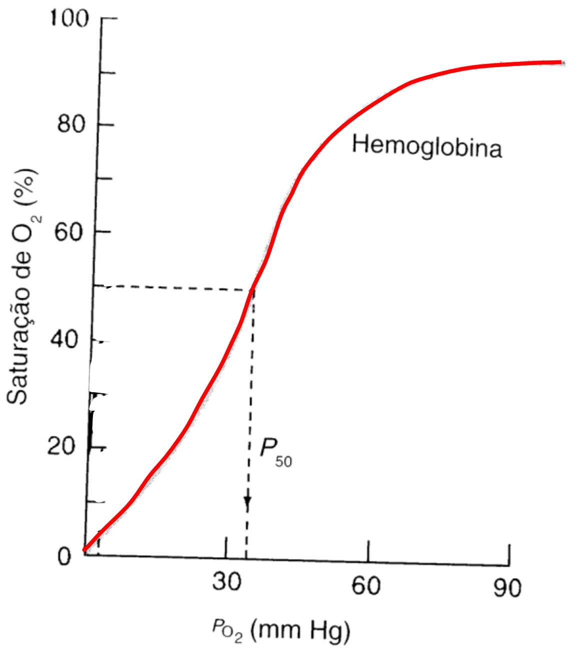
HHb + O_2 → HbO_2 + H^+

PO_2 baixa → pequena quant. de O_2 ligado a Hb.

PO_2 alta → grande quant. de O_2 ligado a Hb.

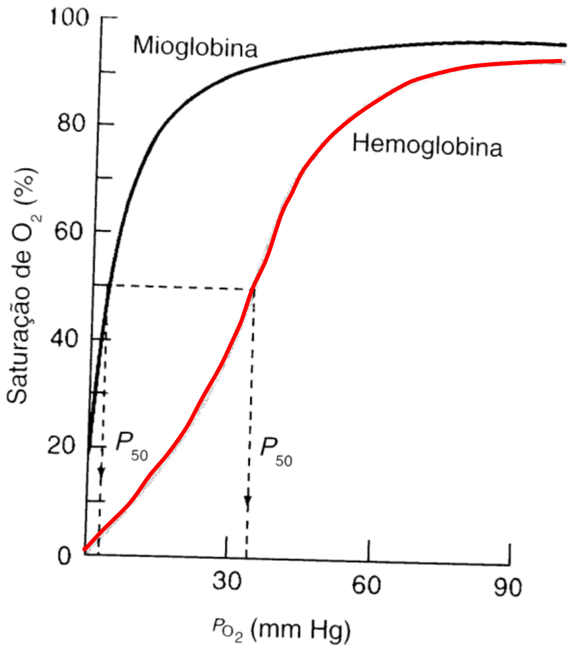


Curvas de dissociação de Oxigênio

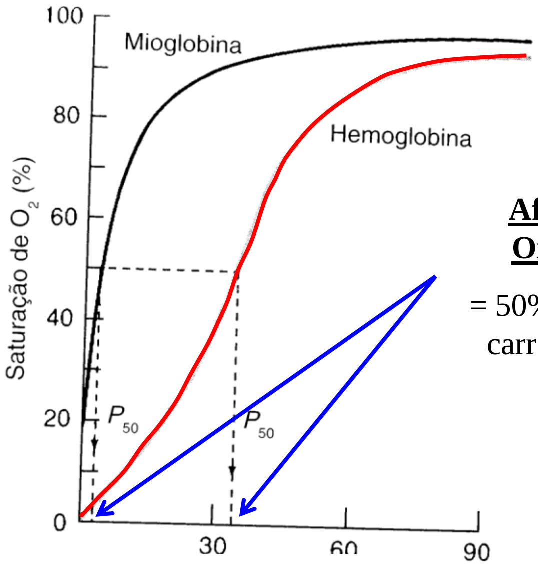


"Eckert" 2000

Curvas de dissociação de Oxigênio



"Eckert" 2000

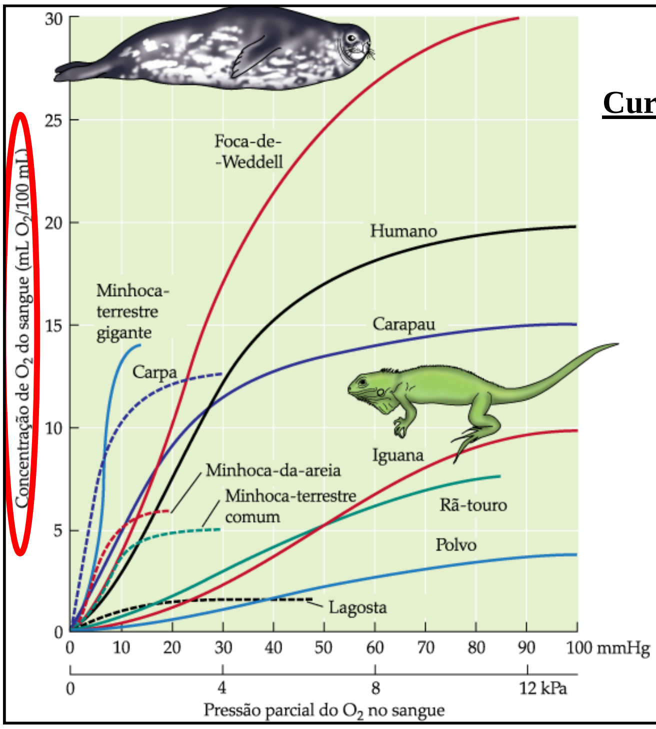


MAIS **MENOS**
AFINIDADE

Afinidade pelo Oxigênio (P_{50})

= 50% dos pigmentos carregados com O_2

"Eckert" 2000



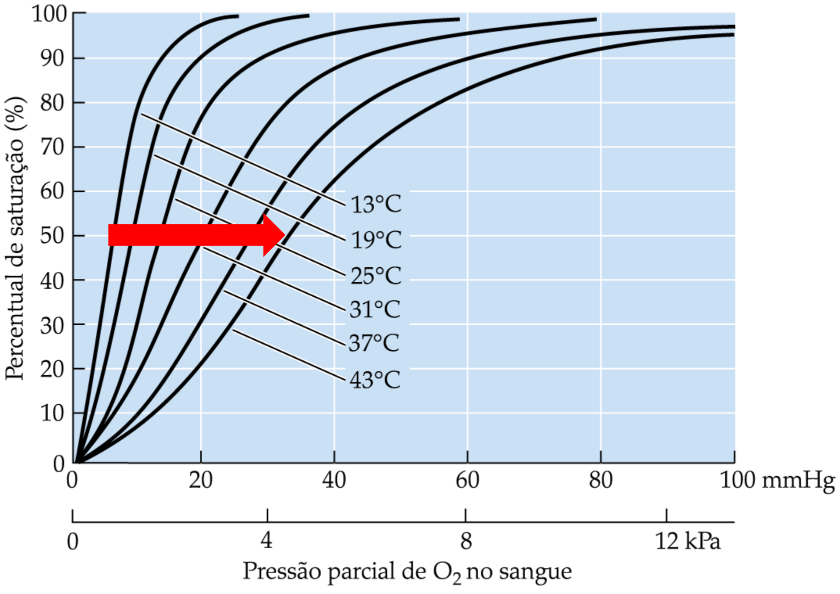
Curvas de dissociação de Oxigênio

Hill et al., 2012

Afinidade pelo Oxigênio (P_{50})

reduzida quando:

- Temperatura elevada

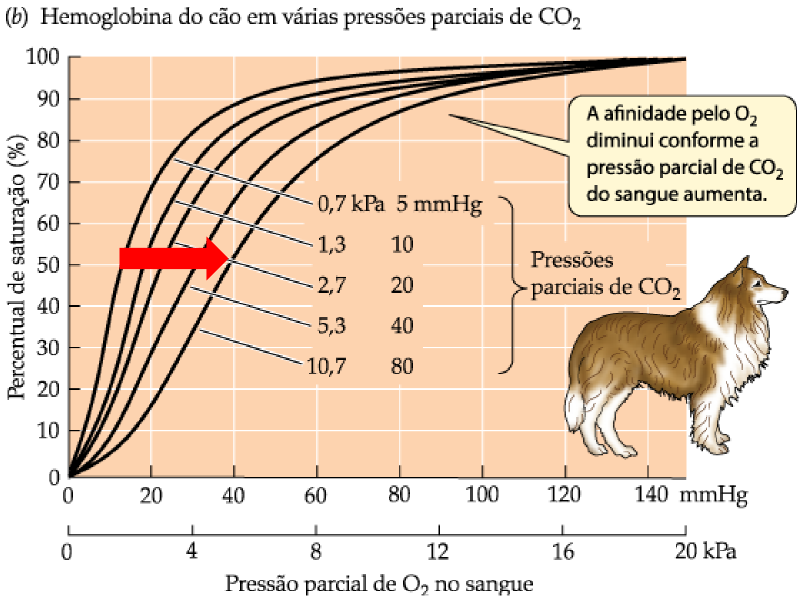


Hill et al., 2012

Afinidade pelo Oxigênio (P_{50})

reduzida quando:

- Temperatura elevada
- aumento no CO_2

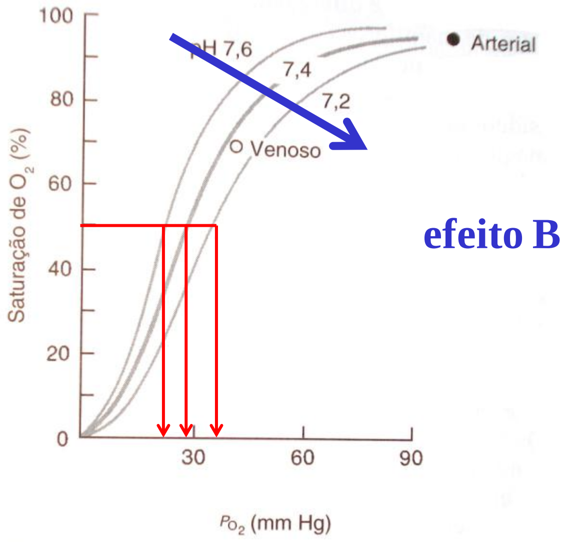


Hill et al., 2012

Afinidade pelo Oxigênio (P_{50})

reduzida quando:

- Temperatura elevada
- aumento no CO_2
- diminuição do pH (H^+ aumenta) → **efeito BOHR**

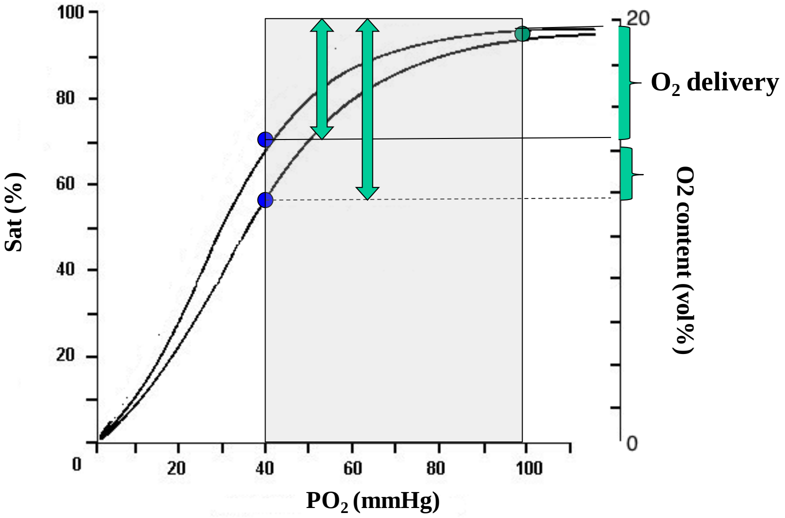


efeito BOHR

Fig. 13.4 A afinidade da hemoglobina pelo oxigênio diminui com a diminuição do pH. Em virtude desse fenômeno, chamado efeito Bohr, mudanças na P_{CO_2} sanguínea, que influencia o pH sanguíneo, afetam indiretamente a afinidade da hemoglobina pelo oxigênio. São mostradas as curvas de dissociação do oxigênio sanguíneo experimentais em humanos em três valores de pH. Os valores da P_{O_2} do sangue arterial misturado com o venoso estão indicados. (Adaptado de Bartels, 1971.)

"Eckert" 2000

Bohr effect – Hb-O_2 equilibrium curve



$V\ O_2 = Q \cdot (\ CaO_2 - CvO_2\ )$

Decreased Hb-O_2 affinity improves tissue O_2 supply

Afinidade pelo Oxigênio (P_{50})

reduzida quando:

- Temperatura elevada
- aumento no CO_2
- diminuição do pH (H^+ aumenta) → **efeito BOHR**
- ligação de fosfatos orgânicos (ATP, GTP, DPG)

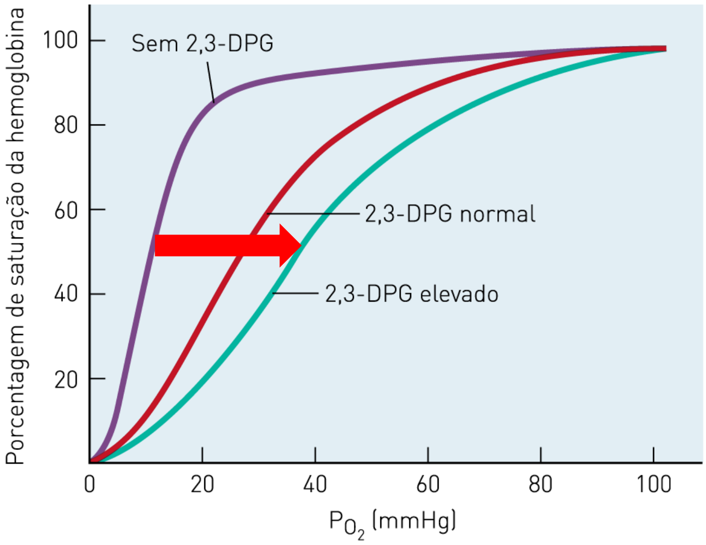
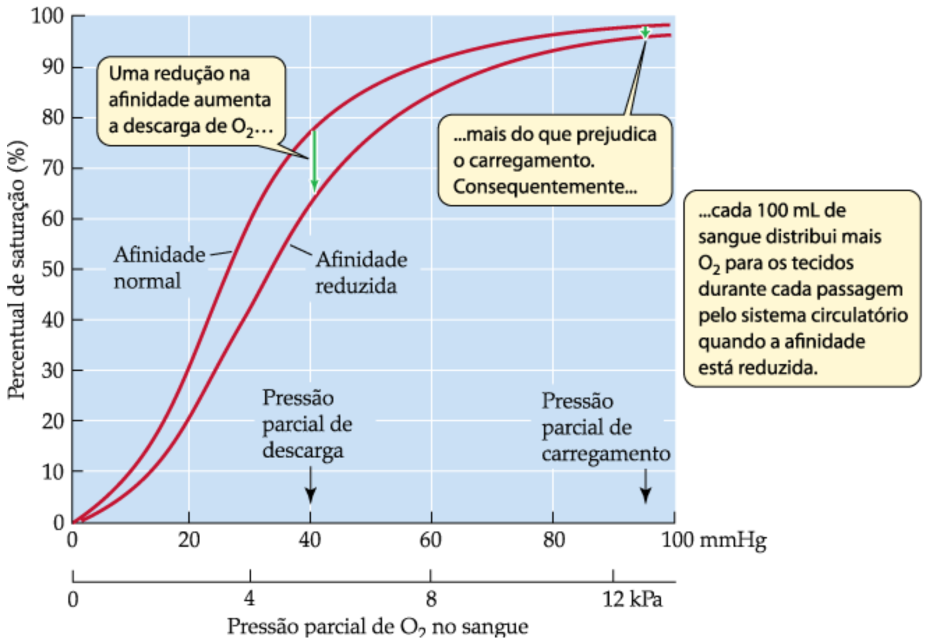


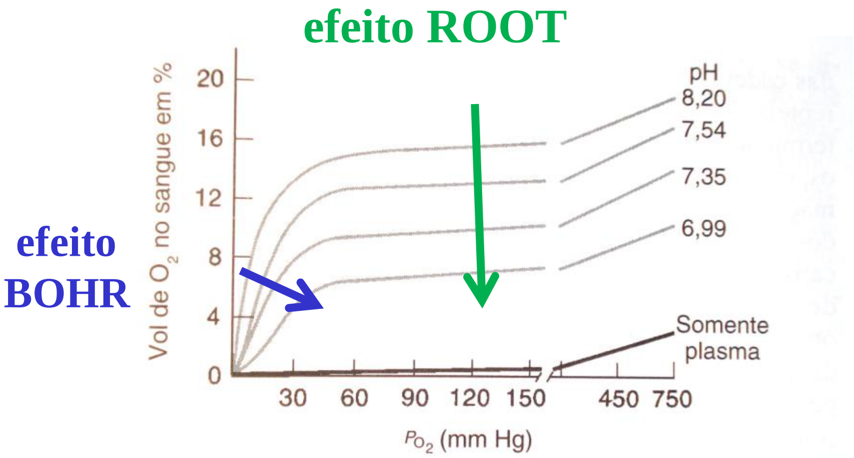
Figura 9.35 **Modulação alostérica da afinidade da hemoglobina pelo oxigênio.** Efeitos do modulador orgânico 2,3-DPG na curva de dissociação de oxigênio da hemoglobina de mamíferos.

Moyes, Schultz, 2010



Hill et al., 2012

Em Peixes:



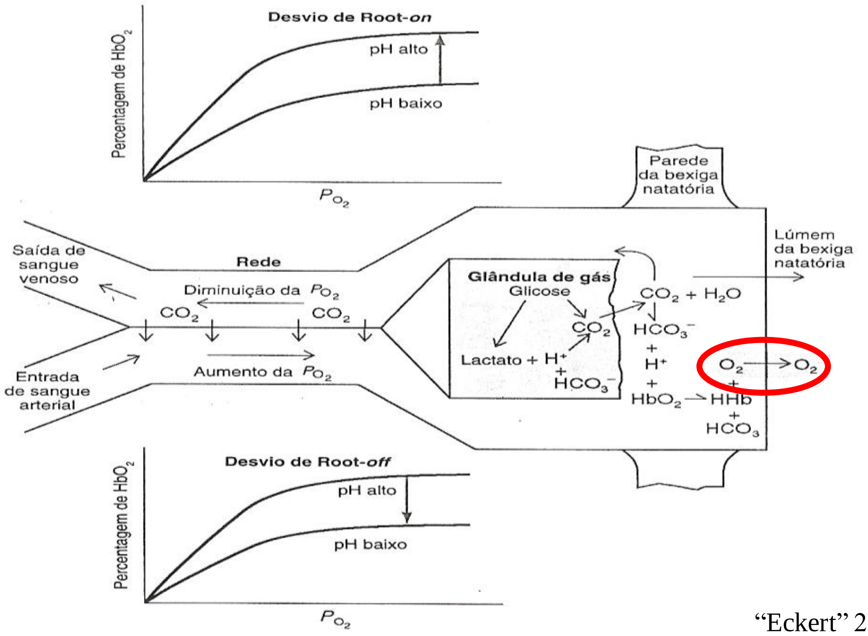
efeito ROOT

efeito BOHR

Fig. 13.6 Reduções no pH diminuem a capacidade de oxigenação do sangue (efeito Root) nas hemoglobinas de alguns peixes teleósteos. Essas curvas de equilíbrio do oxigênio do sangue da enguia foram obtidas a 14°C com pH de 6,99 a 8,20. A linha inferior descreve o conteúdo de O_2 do plasma. (Adaptado de Steen, 1963.)

"Eckert" 2000

Efeito Root na Bexiga natatória



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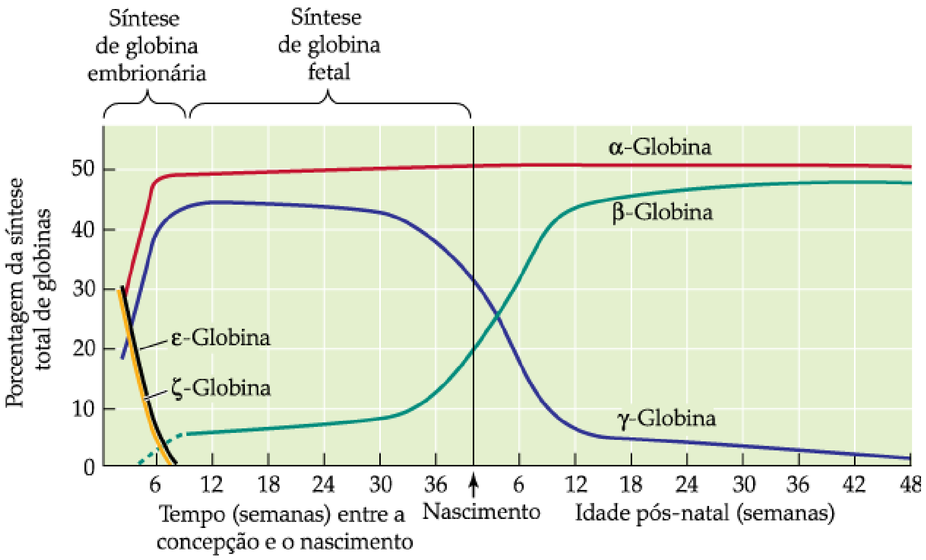
Variações nas subunidades da hemoglobina durante o desenvolvimento



Hill et al., 2012

Afinidade do sangue pelo O_2 e antes e após o nascimento

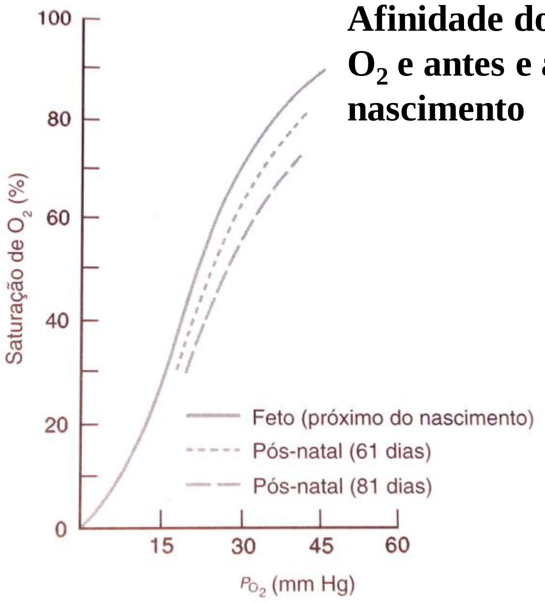


Fig. 13.8 Em humanos, a afinidade do sangue pelo oxigênio diminui por volta dos três meses após o nascimento, à medida que a hemoglobina fetal é substituída pela hemoglobina adulta (veja Fig. 13.7). Essas curvas de dissociação do oxigênio do sangue foram determinadas em um pH de 7,40. (Adaptado de Bartels, 1971.)

"Eckert" 2000

Transporte de CO_2 no sangue:

$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$

$H_2O \leftrightarrow H^+ + OH^-$ $CO_2 + OH^- \leftrightarrow HCO_3^-$

$CO_2 : H_2CO_3$ $CO_2 : HCO_3^-$

1000 : 1 1 : 20

- Formação de carbamino com grupo $-NH_2$ de proteinas (principalmente com Hb)
- Conteúdo total de CO_2 → varia com PCO_2
- Anidrase carbônica
- Desvio de cloretos

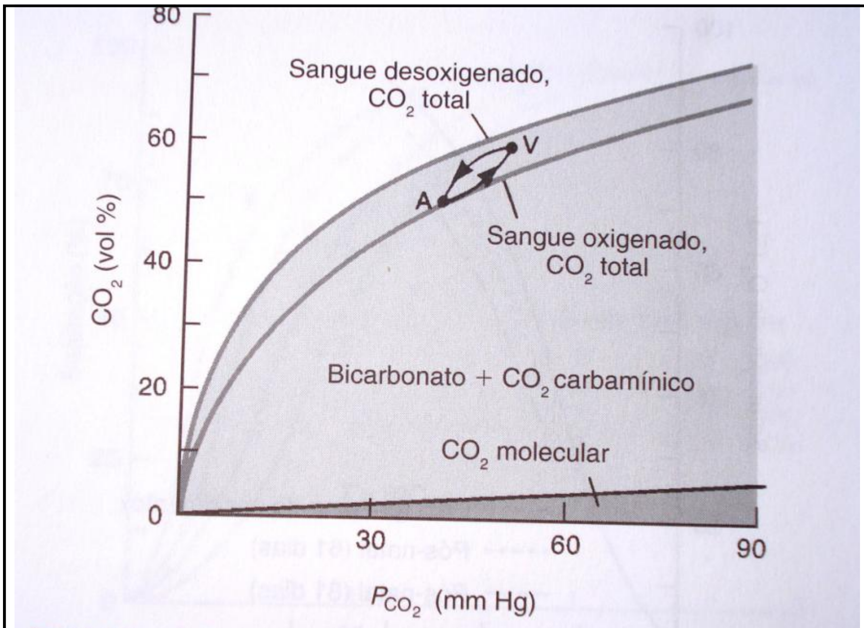
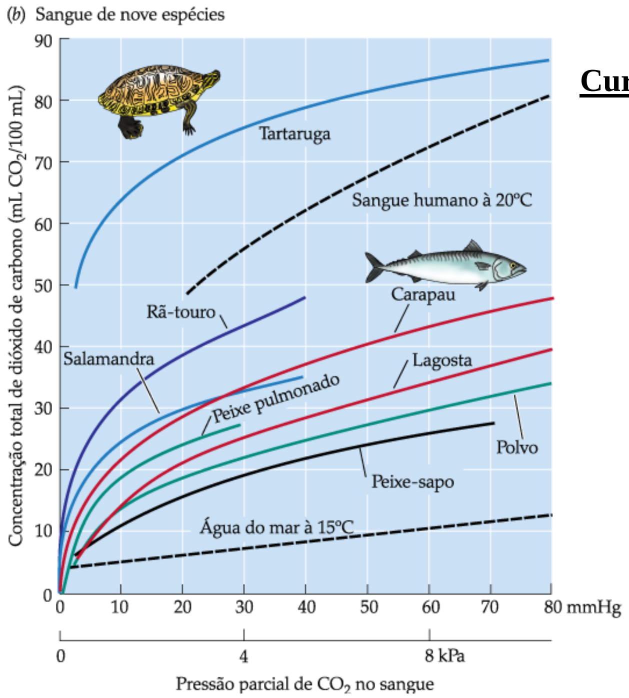


Fig. 13.9 O conteúdo total de CO_2 do sangue aumenta com a P_{CO_2}, mas somente o volume de CO_2 molecular aumenta linearmente. Note que em dada P_{CO_2} o sangue oxigenado contém menos CO_2 que o sangue desoxigenado (efeito Haldane). A e V se referem aos níveis sanguíneos arterial e venoso, respectivamente

"Eckert" 2000

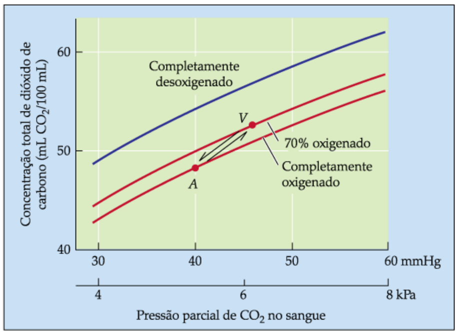


Curvas de dissociação de CO_2

Hill et al., 2012

Efeito Haldane

= mudança na curva de dissociação de CO_2 com o estado de oxigenação do pigmento respiratório



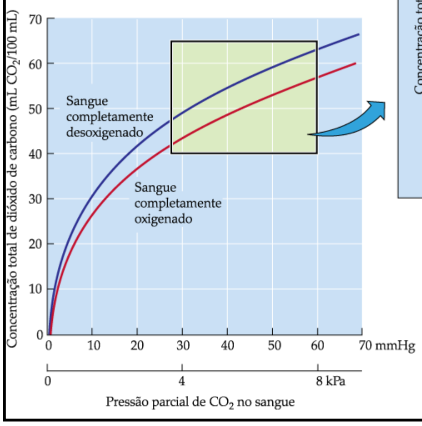
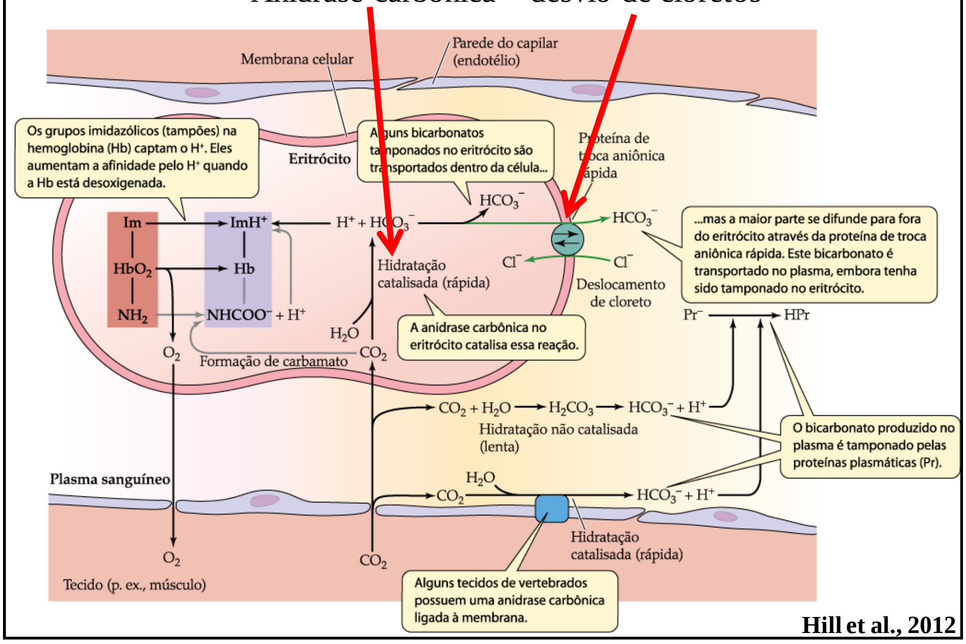


Figura 23.21 O efeito Haldane e suas implicações para o transporte de dióxido de carbono em humanos O gráfico principal (esquerda) mostra as curvas de dissociação do dióxido de carbono para o sangue humano completamente oxigenado e completamente desoxigenado, ilustrando o efeito Haldane. O detalhe (acima) resume o *transporte* de dióxido de carbono em humanos em repouso. O ponto *A* representa o sangue arterial, que está completamente oxigenado e apresenta uma pressão parcial de CO_2 de cerca de 5,3 kPa (40 mmHg). O ponto *V* representa o sangue venoso misto, que se encontra cerca de 70% oxigenado e apresenta pressão parcial de CO_2 de cerca de 6,1 kPa (46 mmHg). As setas mostram a relação funcional entre a concentração de dióxido de carbono e a pressão parcial de CO_2 conforme o sangue circula pelo corpo, tornando-se alternadamente arterial (*A*) e venoso (*V*).

Hill et al., 2012

Trocas gasosas nos tecidos

Anidrase carbônica – desvio de cloretos



Os grupos imidazólicos (tampões) na hemoglobina (Hb) captam o H$^+$. Eles aumentam a afinidade pelo H$^+$ quando a Hb está desoxigenada.

Alguns bicarbonatos tamponados no eritrócito são transportados dentro da célula...

...mas a maior parte se difunde para fora do eritrócito através da proteína de troca aniônica rápida. Este bicarbonato é transportado no plasma, embora tenha sido tamponado no eritrócito.

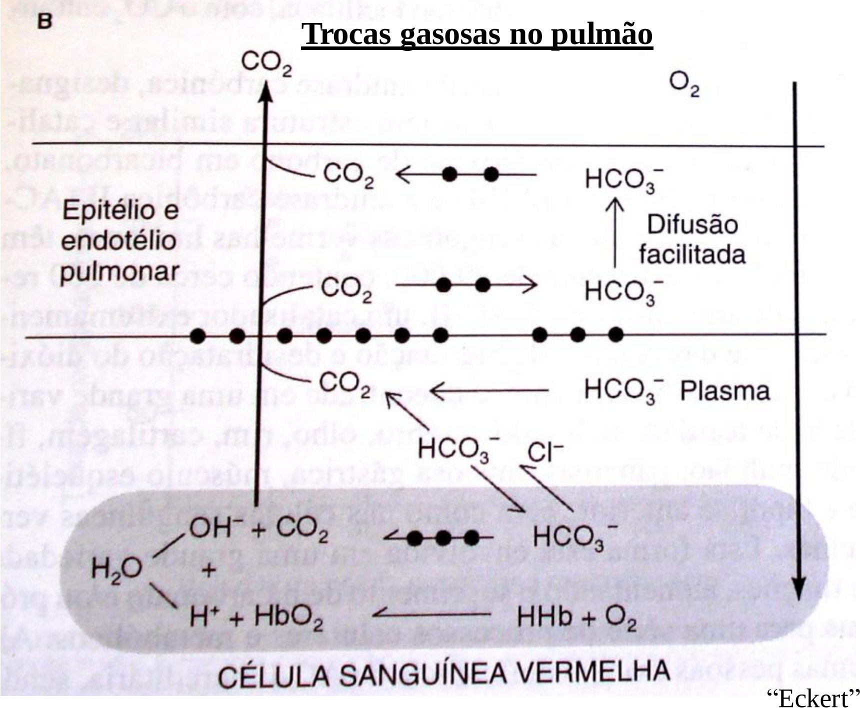
A anidrase carbônica no eritrócito catalisa essa reação.

O bicarbonato produzido no plasma é tamponado pelas proteínas plasmáticas (Pr).

Alguns tecidos de vertebrados possuem uma anidrase carbônica ligada à membrana.

Hill et al., 2012

Trocas gasosas no pulmão



“Eckert” 2000

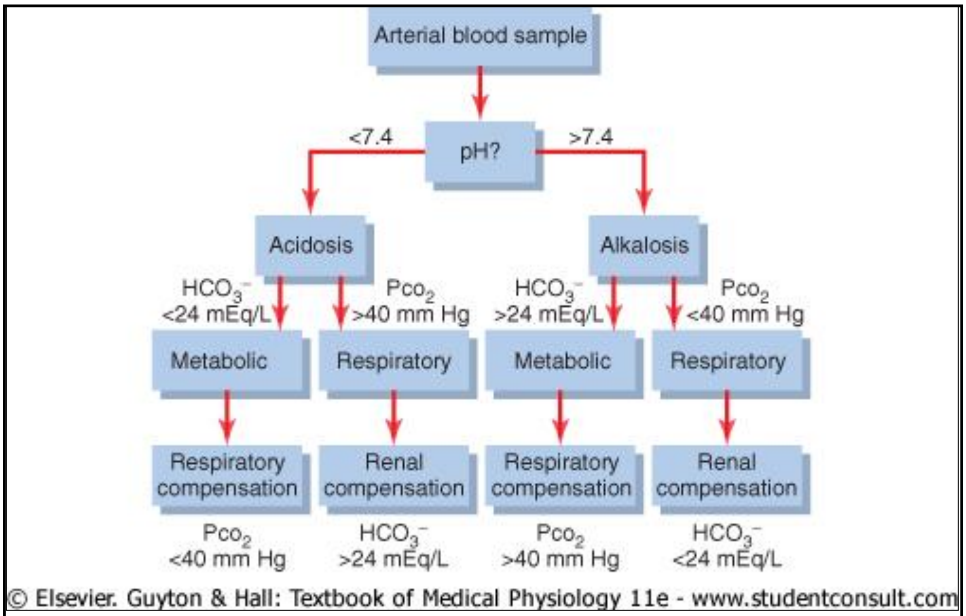


Figure 30-10 Analysis of simple acid-base disorders. If the compensatory responses are markedly different from those shown at the bottom of the figure, one should suspect a mixed acid-base disorder.

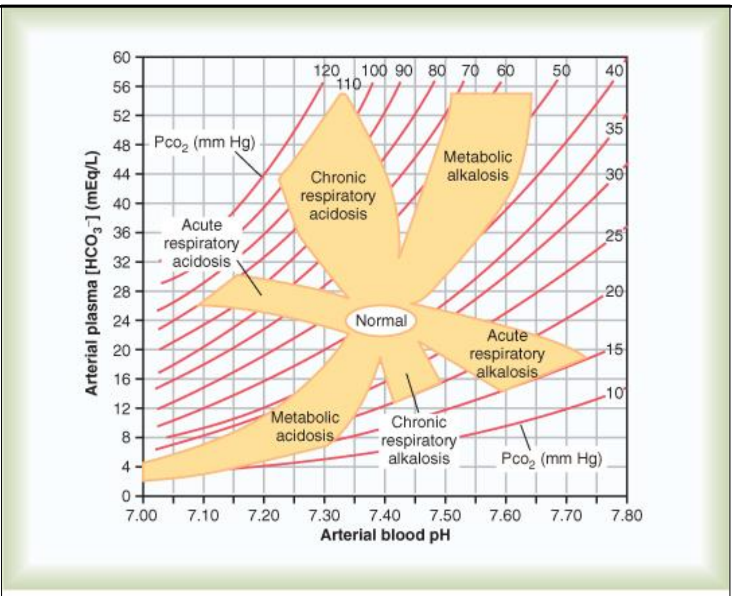
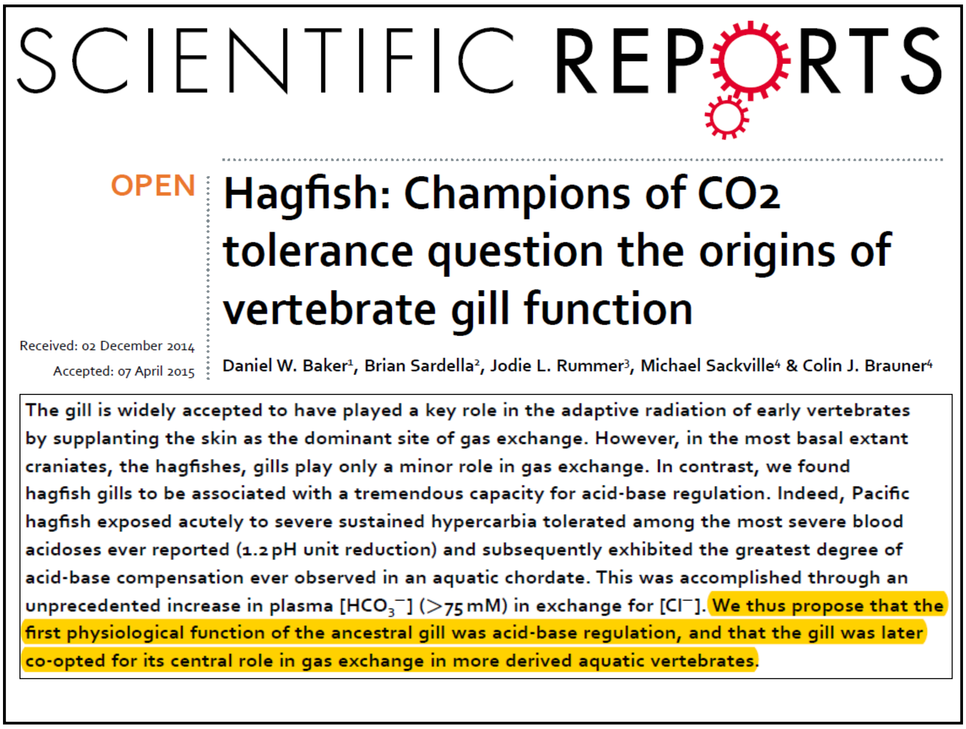


Figure 30-11 Acid-base nomogram showing arterial blood pH, arterial plasma HCO^{3-}, and P_{CO2} values. The central open circle shows the approximate limits for acid-base status in normal people. The shaded areas in the nomogram show the approximate limits for the normal compensations caused by simple metabolic and respiratory disorders. For values lying outside the shaded areas, one should suspect a mixed acid-base disorder.



SCIENTIFIC REPORTS

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Hagfish: Champions of CO2 tolerance question the origins of vertebrate gill function

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The gill is widely accepted to have played a key role in the adaptive radiation of early vertebrates by supplanting the skin as the dominant site of gas exchange. However, in the most basal extant craniates, the hagfishes, gills play only a minor role in gas exchange. In contrast, we found hagfish gills to be associated with a tremendous capacity for acid-base regulation. Indeed, Pacific hagfish exposed acutely to severe sustained hypercarbia tolerated among the most severe blood acidoses ever reported (1.2 pH unit reduction) and subsequently exhibited the greatest degree of acid-base compensation ever observed in an aquatic chordate. This was accomplished through an unprecedented increase in plasma [HCO_3^-] (>75 mM) in exchange for [Cl^-]. We thus propose that the first physiological function of the ancestral gill was acid-base regulation, and that the gill was later co-opted for its central role in gas exchange in more derived aquatic vertebrates.