Medical Hypotheses (2001) **56**(4), 513–518

doi: 10.1054/mehy.2000.1256, available online at http://www.idealibrary.com on IDEAL®

The rise in the atmospheric concentration of carbon dioxide and the effects on human health

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Summary The potential effects on the health of future generations of humans, and other mammals arising from the increase in the concentration of carbon dioxide in the atmosphere, resulting from the use of large amounts of fossil fuels by industrialized societies, is considered. It is concluded that the change in the gaseous composition of the atmosphere will lead to a decline in the health of humans and may well lead to serious population reductions.

INTRODUCTION

It appears that there is no awareness that global warming is not the most serious result of a rise in the concentration of carbon dioxide (CO_2) in the atmosphere. There is a limit to the emission of CO_2 to the atmosphere on the grounds that above a particular concentration of this gas in the atmosphere the physical well-being of all humans and other mammals will be affected. The contribution of the growing human population to global warming and the subsequent effects arising from environmental change on the general health of populations have been considered (1). However, to date, no one has considered that the rise in CO_2 in the atmosphere is a direct threat to human life, i.e. the gas may well have long-term toxic effects.

KNOWN EFFECTS OF EXPOSURE TO AN INCREASED CONCENTRATION OF CARBON DIOXIDE IN THE ATMOSPHERE

There have been extensive studies of the effects of extended exposure of humans to CO_2 gas in concentrations which were very much higher than exist in the present atmosphere. These concentrations occur in closed systems such as submarines and spacecraft. In 1971, NASA carried out a 90-day study of the effects of exposure of humans to 0.5% atmosphere content of CO_2, i.e. 15 times the present atmosphere level (2). This showed significant alterations in the calcium and phosphorus body patterns leading to bone degradation and the deposition of calcium in the body tissues. Such a result can be fatal. Ninety days is a very small fraction of a human lifetime. The presently accepted safe working limit of CO_2 concentration in any atmosphere in which humans work is fifteen times the amount now in the atmosphere. This limit is for exposure of only a few weeks at a time and humans exposed to such levels can take weeks to fully recover after exposure ceases. The important point is not the instantaneous toxic or short-term toxic levels of CO_2 which are important. It is accepted that these levels will not be produced in the atmosphere by human activities. The question arises as to the effects of exposure for a human lifetime to an atmospheric concentration of CO_2 which is lower than toxic levels but still higher than at present times.

Received 24 July 2000
Accepted 16 October 2000

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METABOLIC EFFECTS OF INCREASED CARBON DIOXIDE IN THE ATMOSPHERE

The most important fluid in the body of all animals is the blood and this always has a particular acidity. If this changes, haemoglobin, enzymes and other functional chemicals of the body can be destroyed. The measured acidity of the blood of present day humans has a pH value in the range 7.35 (veins) to 7.45 (arteries). These values can vary in this range which allows humans to operate under the normal changes in the atmospheric CO_2 concentration of present times. The daily change in the atmospheric concentration of CO_2 can be intermittently as high as 30% in some regions (3). The overall change annually over the land masses of the northern hemisphere is not as high at about +/– 5% from the present mean value of 353 p.p.m. (4). The latter value is 26% higher than the mean value of 280 p.p.m. prior to industrialization (4). When the pH value of the blood increases above 7.45 units to 7.6 units the blood is becoming more alkaline, leading to a condition called alkalosis and when it falls to 7.2 units the blood is becoming more acid leading to acidosis. Both conditions are detrimental to human health and can be fatal.

The important change induced by an increased CO_2 content of the atmosphere is in the acidity of the blood. It is known that, under conditions where there is an increase in the concentration of CO_2 in the lungs, such as in the case of chronic bronchitis, the pH value of the blood declines and under conditions of the expelling of more than normal air from the lungs, such as can occur in hyperventilation, there is an increase in the pH of the blood. The acidity of the blood is considered to be controlled principally by the chemical reaction leading to the formation of bicarbonate ions from CO_2 and water in the blood stream. CO_2 is formed in blood, either by the oxidation of organic compounds such as the oxidation of alcohols through aldehydes to acids and finally to CO_2 and water, or the reaction of acids formed by the metabolism with carbonates present in the body fluids. The gas dissolves in the aqueous component of the blood forming carbonic acid. This process is enhanced by the enzyme carbonic anhydrase. This reaction proceeds as follows:

$$CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ \, HCO_3^- \Leftrightarrow 2H^+ + CO_3^- \quad (1)$$

The pH value of the blood is calculated from an equation derived from the above reaction and known as the Henderson–Hasselbalch equation:

$$pH = pK + \log ([HCO_3^-]/[CO_2] \quad (2)$$

The value of the term $[HCO_3^-]$ is usually measured and the value of the term $[CO_2]$ is evaluated on the basis of the partial pressure of the CO_2 dioxide in the lungs from Dalton's Law and the variation of the solubility of CO_2 dioxide with varying partial pressure according to Henry's law. A typical value for the former is 24 millimoles litre^{-1} and for the latter is 0.03 millimoles Torr^{-1} and pK has the value 6.1. The partial pressure value of CO_2 used in the equation is that in the lungs which is taken to have a value of 40 Torr. When these values are used in the Henderson–Hasselbalch equation, the value of the pH of blood obtained is 7.402.

The concentration of CO_2 in the lungs attains a value of 5.6% or 56 000 p.p.m. compared with the value of 353 p.p.m. in the atmosphere. Under conditions where there is a rise of 100 p.p.m. in the atmospheric concentration of CO_2 the change in pH is estimated using the Henderson–Hasselbalch equation with the values given above. Value of the CO_2 concentration in the blood is now 5.61% and using this to evaluate the change in blood pH a value of 7.401 is obtained leading to the conclusion that a rise in the atmospheric concentration of CO_2 of 100 p.p.m. from the present value of 353 p.p.m. to 453 p.p.m. does not affect humans. Since the concentration of CO_2 is rising at a rate of 1.16 p.p.m. annually due to human activities then the latter value will be reached about 2050 AD. Alternatively, the accepted toxic limiting concentration of CO_2 in the atmosphere is 5000 p.p.m. When this value is inserted into the Henderson–Hasselbalch equation using the values listed above then a blood pH value of 7.364 is obtained. This value is again within the pH range of human blood and would lead to the conclusion that even an atmospheric concentration of 5000 p.p.m. of CO_2 would not affect humans, contrary to observation.

However **Equation 1** is strictly correct only for the CO_2 dissolved in pure water where there are no other ions which can form carbonates or bicarbonates. The range of pH values of blood show that blood fluid is alkaline. **Equation 1** does not give rise to the necessary hydroxyl ions to produce this condition since it gives rise to an acid. By definition, an acid is a chemical compound which gives rise only to hydrogen ions when dissolved in water. In addition, the function of the Henderson–Hasselbalch equation is the calculation of the required amounts of components necessary to produce a buffer solution with a particular pH value. The application of the Henderson–Hasselbalch to blood means that blood taken as a buffer solution as opposed to a buffered solution and the results of the calculations given above are to be expected. A buffer solution involves a weak acid, for example acetic acid, and a salt of the same weak acid derived from a strong base, for example sodium acetate. A change in the ratio of the concentration of the salt to the acid will cause an alteration in the pH at which the buffer solution operates. In blood the weak acid is taken as carbonic acid and implied salt of a strong base is sodium bicarbonate. The concentration of the carbonic acid changes during the circulation of the blood and the pH of blood varies between 7.35 and 7.45. If the concentration of the sodium bicarbonate changed in proportion to the change in carbonic acid concentration, as indicated by **Equation 1**, then the ratio of concentration of salt to that of the weak acid would remain constant and the pH would not change. The conclusion is that blood is not a buffer solution and the application of the Henderson–Hasselbalch equation to blood is invalid. Blood may be buffered by other components present such as monophosphoric acid and phosphates. Under these circumstances, it is the relative amounts of these components which should be inserted into the Henderson–Hasselbalch equation.

Both sodium and potassium ions are present in blood and both these ions form carbonates by reaction with the carbonic acid. The reaction in aqueous solution between the strong base, sodium hydroxide, (NaOH) and carbonic acid produces both sodium carbonate and sodium bicarbonate. In particular the sodium carbonate formed undergoes hydrolysis to give rise to hydroxyl ions. The reactions are as follows:

$$2Na^+ + CO_3^- \Leftrightarrow Na_2CO_3 \quad (2)$$
$$Na_2CO_3 \Leftrightarrow 2Na^+ + CO_3^- \quad (3)$$
$$CO_3^- + H_2O \Leftrightarrow HCO_3^- + OH^- \quad (4)$$
$$HCO_3^- \Leftrightarrow OH^- + CO_2 \quad (5)$$

The hydrolysis of sodium carbonate formed from the reaction of sodium ion present blood with dissolved carbon dioxide is the origin of blood being alkaline in nature. A solution of sodium bicarbonate in water is hydrolysed to a much lesser extent than is the case for a solution of sodium carbonate in water. The effect of increasing CO_2 gas in the solution is to drive the above series of reactions in the reverse direction beginning with the right hand side of **Equation 5** and moving to finish at the left hand side of **Equation 3**. Progressively more CO_2 enters the blood as the blood passes from the arteries to the veins reducing the hydroxyl ion concentration and increasing bicarbonate concentration according to the equations above. The reduction in hydoxyl ion concentration increases the hydrogen ion concentration and results in a lowering of the pH value of the blood. That this occurs in blood is demonstrated by the difference of pH between the blood in the veins and arteries. The important reactions controlling the acidity of blood are therefore the reversible reactions given by **Equations 3–5** above involving the change from bicarbonate to carbonate.

The amount of bicarbonate formed can be estimated from the known ion concentrations in blood. Sodium ion concentration in blood is 140 meq litre^{-1} equivalent to 3.21 g litre^{-1} and chlorine ion concentration in blood is 100 meq litre^{-1} equivalent to 3.54 g litre^{-1}. The major compound present in blood will be sodium chloride and this will use 2.29 g litre^{-1} of Na^+ and all of the Cl^- ion. The amount of Na^+ ion left for bicarbonate/carbonate reaction is then 0.92 g litre^{-1} which will give rise to 2.13 g litre^{-1} of sodium carbonate and will require 1.205 g of carbon dioxide. On hydrolysis this amount of sodium carbonate will give rise to 1.226 g litre^{-1} of bicarbonate ion which is equivalent to 20.1 meq litre^{-1}. The potassium ion contributes 2.1 meq litre^{-1} of bicarbonate ion giving the total of bicarbonate ion as 22.2 meq litre^{-1}. This theoretical value of bicarbonate ion is in reasonable agreement with the measured value of 24 meq litre^{-1}.

The appearance of a substantial concentration of carbonate ions as the result of changes in the pH value of blood will have serious effects. The differences in the solubilities of the sodium and potassium carbonates and bicarbonates have to be considered. The solubility values for these compounds at 37˚C are:

Sodium carbonate	Solubility = 71 g litre^{-1}
Sodium bicarbonate	Solubility = 69 g litre^{-1}
Potassium carbonate	Solubility = 1120 g litre^{-1}
Potassium bicarbonate	Solubility = 224 g litre^{-1}

It can be seen from these figures that the formation of carbonate ion progressively increases the salt content of the human body to a limiting increase of 3% and increases the potassium content to a limiting increase of 500%. Potassium is an important ion in human cells as Table 1 (5) demonstrates and progress towards the limiting increase would progressively disrupt the body function through interference with the cell functions and changes in the nature of the buffer chemicals in the body.

It is a widely held conclusion that changes in pH produce or are associated with changes in serum potassium concentrations. A decrease in the pH value of blood has been reported to lead to an increase in the potassium concentration of this body fluid and also the reverse is

Table 1 Cellular ion content

Extracellular ion concentration Milliequivalents / litre				Intracellular ion concentration Milliequivalents / litre			
Cations		**Anions**		**Cations**		**Anions**	
Na+	140	Cl–	105	Na+	10	Cl–	2
K+	4	HCO3–	25	K+	150	HCO3–	8
Mg++	2	PO4–	2	Mg++	25	PO4–	95
Ca++	5	SO4–	1	Ca++	3	SO4–	25
		Protein	12			Protein	55
		Organic acid	6			Organic acid	8

Data from reference 3.

stated to occur. This conclusion has been challenged on the grounds that factors which may alter potassium balances often act in conjunction with pH changes making the clear case for pH to be the principal factor undecided. Nevertheless, it is accepted that wide differences in plasma potassium concentrations occur in association with various acid-base disorders and that blood pH appears to be one of the many factors altering plasma potassium concentrations (*6*). However, the appearance of carbonate ion in the body fluids would have the effect of altering the potassium content of body fluids on the basis of the fact that as more carbon dioxide dissolves or remains in blood the pH value of blood falls. This results in the formation of the more soluble potassium carbonate more of which can dissolve in the blood from the source of this element in the food supply.

RESPIRATORY EFFECTS OF AN INCREASED CONCENTRATION OF CARBON DIOXIDE IN THE ATMOSPHERE

It has been advanced that even a doubling of the present concentration of CO_2 in the atmosphere will have no effect on human health since the change will be countered by a rise in respiration rate. The observed reflex in response to high CO_2 levels (decrease in pH value) is increased respiratory rate and depth as the result of sympathetic neural stimulation and release of adrenal catecholamines leading to an increased heart rate and vasoconstriction of blood vessels to organs least in need of blood. For CO_2 to leave the blood the partial pressure of the gas above the solution must fall to a point where the amount dissolved in the blood exceeds solubility limit in blood at this partial pressure. The mechanical function of respiration removes CO_2 from the lungs as the result of exhalation and reduces the partial pressure of this gas above the solution of CO_2 in blood to a value where CO_2 leaves the blood. The volume of air entering or leaving the lungs in the 4-second period of one breath of inhalation or exhalation is the tidal volume. This has the value of 0.5 litre and 0.35 litre enters the lungs. At the end of the 4-second exhalation period, 97% of the gas in the lungs exits the lungs leaving a volume of gas in the lungs of 10.5 ml. The partial pressure of the carbon dioxide is now 1.2 Torr. The incoming air, should it contain no CO_2, would dilute this remaining CO_2 further, giving a minimum partial pressure of this gas of 0.036 Torr. The minimum partial pressure of CO_2 in the lungs would be less than that in the atmosphere. However, the gas entering the lung by inhalation has a CO_2 partial pressure of 0.216 Torr. Any CO_2 dissolved in the blood in excess of the solubility value at the atmospheric partial pressure of CO_2 leaves the blood. The rise of CO_2 in the lungs to a partial pressure of 40 Torr, as a result of restricted flow of the gas to the atmosphere, gives rise to a corresponding rise in the solubility limit and the loss of CO_2 from the blood slows down. This continues until the next exhalation occurs. This oscillatory action maintains the functioning of the metabolic reactions in the blood by the removal of a reaction product in accordance with the Law of Mass Action. The solubility of CO_2 in water at NTP and 37°C (310° Kelvin) is 1.0 g litre^{-1}. The amount of CO_2 used to form the sodium carbonate is 1.2 g. Free CO_2 arises from the hydrolysis of the sodium carbonate. Hydrolysis of the amount sodium carbonate (2.542 g litre^{-1}) giving rise to the measured amount of bicarbonate ion (24 meq litre^{-1} = 1.464 g litre^{-1}) releases 1.056 g litre^{-1} of CO_2. Thus, at least 0.056 g of carbon dioxide is lost from every litre of blood flowing through the lungs. That this value is of the correct order is shown by the fact that the weight of CO_2 in the lungs when exhalation commences is 0.036 g. This estimation is based on the lung volume of 350 ml, a partial pressure of CO_2 of 40 Torr and a total pressure of 760 Torr. The last figure assumes that the addition of CO_2 to the gas in the lungs is countered by the loss of oxygen to the bloodstream. The loss of CO_2 from the blood moves the **Equation 5** to the right and results in the formation of hydroxyl ion. This reduces the hydrogen ion concentration and the pH value of the blood increases towards 7.45. The pH of blood varies between 7.35, when CO_2 has been added to the blood during passage through the body, to 7.45, when CO_2 is removed from the blood in the lungs, as observed. The above demonstrates that partial pressure of carbon dioxide in the atmosphere ultimately controls the amount of CO_2 in the blood. Chemicals which can function as buffer chemicals and considered to be present in blood are phosphates of sodium and potassium operating in conjuction with a weak acid, such as monophosphoric acid, as required by the Henderson–Hasselbalch equation. A standard disodium hydrogen phosphate–citric acid buffer solution can control the pH of a solution over a range of values from pH 2.2 to a pH of 8.0 depending on the concentration of the disodium hydrogen phosphate used. It follows that the buffer chemicals of the body will alter in pH control characteristics if and when the concentration of the buffer chemical changes as will happen under conditions where concentration of the alkali metal ions in the blood changes due to the solubility differences given above.

THE CONCENTRATION RANGE OF ATMOSPHERIC CARBON DIOXIDE TOLERABLE BY HUMANS

The rate of rise of CO_2 in the atmosphere at present is 1.16 p.p.m. annually, giving a value of 425.8 p.p.m. in the year 2050 AD. Under circumstances where the amount of CO_2 in the atmosphere increased from the present

353 p.p.m. to 425.8 p.p.m., a rise of 20.6%, the amount of CO_2 retained by the blood would increase and the equilibrium of the reaction given in **Equation 5** would move towards the formation of a higher proportion of carbonate. The consequence is a permanent change of the ratio of bicarbonate to carbonate as a result of less CO_2 leaving the blood caused by the higher partial pressure in the atmosphere and a corresponding rise in the solubility of CO_2 in the blood. A pH value of 7.4 represents 3.98×10^{-8} g ion litre^{-1} of hydrogen ions. An increase in the atmospheric concentration of CO_2 by 20.6% and would reduce the hydroxyl ion concentration and increase the hydrogen ion concentration by this amount, giving a pH value of 7.319. This value is just outside the range of normal pH values of human blood and indicates the onset of acidosis. The CO_2 concentration prior to industrialization was 280 p.p.m. (4). This is 20% below the present value. Under these conditions, the CO_2 has been removed from **Equation 5** and the bicarbonate and hence the hydroxyl ion would have increased. This reduces the hydrogen ion concentration and the value of the pH of the blood of humans prior to industrialization was 7.49. or just outside the upper limit of 7.45 in present-day humans. These values demonstrate that humans can survive a change in the atmospheric concentration of about +/– 20% from the present value of 353 p.p.m.

The amount of CO_2 than can dissolve and remain in the blood under the new value of the CO_2 partial pressure in the atmosphere has permanently increased. In order to counter the change, a permanent increase in the natural depth of respiration, but not necessarily the respiration rate, would be required to lower the minimum partial pressure to that of the present time. This removes CO_2 in the blood to the point where the concentration remaining in the blood was the same as at present. Hence the pH of the blood would be maintained at that of present times. This would have to be achieved either by an evolutionary change in human metabolism or by a conscious effort. Under the latter conditions, every human on the planet would have to continually and consciously deep-breathe. This condition would not be conducive to human health since it would affect the human heart. There is evidence that acidosis or alkalosis has a direct effect on the functioning of the heart (7). The effort required to increase the depth of respiration is much more detrimental to the physical well-being of humans than the reverse which was the case prior to industrialization.

CONCLUSION

It is predicted by the IPCC that the value of the atmospheric concentration of carbon dioxide could reach 720 p.p.m., twice the present concentration, by 2050 AD (8). This takes into account industrialization of nations not yet industrialized to the extent of the Western nations. It is extremely unlikely that such nations will voluntary forego the perceived benefits of industrialization and this figure is almost certain to be attained. The blood pH of all humans would then be in the region where acidosis occurs and every human on Earth will suffer from acidosis for all of their lifetime. Humans born after 2050 AD will begin to show the effects of acidosis from birth. The minimum effects of acidosis are restlessness and mild hypertension. As the degree of acidosis increases, somnolence and confusion follow. The second known effect of acidosis is the development of weaknesses in the bone structure of the body. It follows that a very large number of humans are likely to become incapable of physical activity taken for granted in present times and may be incapable of food production activities even with the help of machines. In consequence of these changes a very large number of humans are likely to die at an early age. The only animals which could successfully survive such an atmospheric level of carbon dioxide are sea mammals, such as seals, whose bodies have evolved to deal with very large amounts of CO_2 in their blood. The effects of an increased atmospheric concentration of carbon dioxide will be enhanced within land continents like the USA, where there are air circulations which mix slowly with other air currents, e.g. from the oceans, at certain times of the year. The effects of the rise in atmospheric CO_2 level will also be enhanced in cities within geographical depressions such as Mexico City and Athens.

It is true that the general health of humans worldwide is greatly improved over that which existed prior to industrialization. As noted above, the present concentration of CO_2 in the atmosphere and the predicted rise to 425.8 p.p.m. by 2050 AD are still within the limits of control by the human body. However, the accompanying changes in blood acidity caused by a rise in the atmospheric content of CO_2 cannot be dismissed as insignificant when there has been no study of this aspect of the change in the atmosphere. At present, there is no effort to establish whether such changes are happening or are likely to happen two or more generations from the present date. Therefore the most serious effect of a rise in the CO_2 content of the atmosphere is not necessarily global warming but the long-term effects on human health. The work above demonstrates that the rise in the atmospheric concentration of CO_2 to the alternative predicted value of 720 p.p.m. cannot be allowed to occur if the health of all humans is be preserved.

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