Eur Respir J
1989, 2, 972–976

Effect of oxygen administration on the breathing pattern during haemodialysis in man

R.M. Heyrman, W.A. De Backer, J.P. Van Waeleghem*, M.J. Willemen, P.A. Vermeire, M.E. De Broe*

Effect of oxygen administration on the breathing pattern during haemodialysis in man. R.M. Heyrman, W.A. De Backer, J.P. Van Waeleghem, M.J. Willemen, P.A. Vermeire, M.E. De Broe.

ABSTRACT: During haemodialysis (HD), allowing important CO_2-unloading, an irregular breathing pattern (BP) is frequently observed. This has been attributed to a decrease in central chemoreceptor firing, with a greater contribution of the peripheral chemoreceptors in the chemical drive to breathe. To provide further evidence for these findings we studied five patients with end-stage renal failure in chronic HD. They underwent HD with a cuprophane membrane and acetate-containing dialysate. Ventilation was measured continuously using respiratory inductance plethysmography. Oxygen was administered for 30 min, using nasal cannulae, at a rate of 6 $l \cdot min^{-1}$, starting 130 min after the onset of the HD. Blood gases were taken from the arterial line. During the initial air breathing, arterial oxygen tension (Pao_2) decreased from 12.3±1.2 kPa (92.8±8.9 mmHg) at 0 min to 10.5±1.8 kPa (79.0±13.3 mmHg) at 2 h ($p<0.01$) (mean±SD). All patients showed irregular breathing with 1.4±0.6 apnoeas exceeding 10 s per 10 min after 2 h. Minute ventilation decreased from 6.8±1.9 $l \cdot min^{-1}$ at 0 min to 5.4±1.3 $l \cdot min^{-1}$ at 2 h ($p<0.05$). During the O_2 breathing, Pao_2 increased to 26.3±4.0 kPa (197.8±30.3 mmHg) ($p<0.001$), while arterial carbon dioxide tension ($Paco_2$) remained unchanged. The irregular BP previously observed vanished completely. The mean number of apnoeas exceeding 10 s per 10 min decreased to 0.08±0.12 during O_2 ($p<0.002$). There were no other significant changes in the BP and ventilation before and during O_2 breathing. These results suggest that peripheral chemoreceptors contribute to breathing irregularities observed during extracorporeal CO_2 unloading since silencing them with O_2 administration results in a rapid decrease in number of apnoeas.

Eur Respir J., 1989, 2, 972–976

Depts of Pulmonary Medicine and *Nephrology-Hypertension, University of Antwerp (UIA), Antwerp, Belgium.

Correspondence: W.A. De Backer, University Hospital Antwerp, Wilrijkstraat 10, B-2520 Edegem, Antwerp, Belgium.

Keywords: Breathing pattern; control of breathing; haemodialysis.

Accepted after revision July 24, 1989.

A decrease in arterial oxygen tension (Pao_2) is frequently observed during haemodialysis (HD) [1, 2]. Two mechanisms may be involved.

Firstly, the use of a bioincompatible membrane leads to activation of the alternative pathway of the complement system. The resulting intrapulmonary leucocyte aggregation and mediator release causes ventilation-perfusion inequality and arterial hypoxaemia [3, 4]. This phenomenon occurs early in the course of HD and has a rather limited effect on Pao_2.

Secondly, the hypoxaemia can also be accounted for by alveolar hypoventilation consequent to CO_2 loss into the dialysate [5, 6]. This alveolar hypoventilation occurs later in the course of HD, depends upon the type of dialysate used and can have an important effect on Pao_2.

To gain better insight into the mechanisms of alveolar hypoventilation, we recently measured ventilation continuously, using respiratory inductance plethysmography [7–9]. This revealed marked irregularities in the breathing pattern during HD using a bioincompatible membrane and an acetate containing dialysate in which CO_2 is lost. Tidal volume varied from breath to breath, apnoeas exceeding 10 s occurred and sometimes real period breathing emerged [10]. We hypothesized that these irregularities resulted from CO_2 unloading leading to a critical arterial carbon dioxide tension ($Paco_2$) level where the CO_2 response curve became dog-leg shaped and the central chemoreceptors were switched off [11–14]. This made ventilation more dependent on the output of the brisk response of peripheral chemoreceptors to hypoxia.

This may, therefore, lead to a highly unstable situation since the modifying role of the central controlling mechanisms was ruled out and the peripheral chemosensitivity reflexes were stimulated by the simultaneous occurrence of a decreased $Paco_2$ and hypoxia (due to the use of a bioincompatible membrane). We postulated that suppressing the output of the peripheral chemoreceptor through O_2 breathing would restore a more stable breathing pattern.

Patients and methods

The protocol of this study was examined and accepted by the Ethical Committee of the University Hospital. All patients gave their informed consent.

Five patients, aged 20–70 yrs, two men and three women, with end-stage renal failure treated twice weekly for at least six months in a chronic HD programme, were studied. All patients were clinically stable and had normal static and dynamic lung volumes and normal chest radiograph.

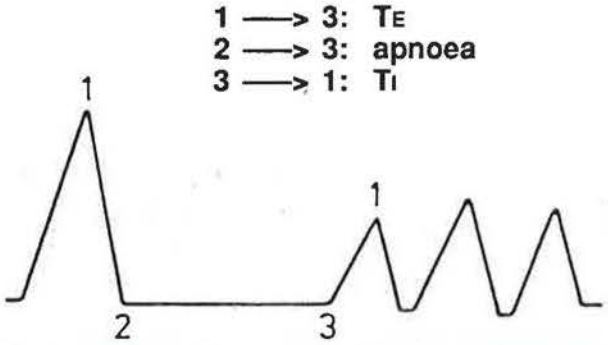

Fig. 1. – Definitions of inspiratory time (TI), expiratory time (TE) and apnoea.

HD was performed using a bioincompatible cuprophane membrane (Gambro LP, A m^2, AB Gambro, Lund, Sweden) and an acetate-containing dialysate. An open, two-needle, single-pass system with controlled ultrafiltration was used. Ventilation and breathing pattern were measured continuously using respiratory inductance plethysmography (RIP). Measurements were started approximately 15 min before HD. RIP was calibrated by multiple regression analysis [15] with the patients in a semi-recumbent position in which they remained throughout HD. Calibration was checked after 1 h of measurement for validation and repeated every hour.

After a stabilization period of 2 h of HD the patients were asked to breathe through nasal cannulae. Initially, air was delivered at a flow rate of 6 $l \cdot min^{-1}$ during 10 min to evaluate the effects of the nasal cannulae on the breathing pattern. During the subsequent 30 min O_2 was administered at the same flow rate. This switch was performed single-blind. After this period patients once again breathed air *via* the nasal prongs for another 10 min.

Blood samples were drawn from the arterial line and analysed immediately for blood gas tensions (Corning 175 Automatic) at 0, 60 and 120 min after the start of HD and at 160 min during O_2 breathing.

As described previously [10], breathing patterns were analysed quantitatively for minute ventilation, tidal volume, breathing frequency, inspiratory time (TI), expiratory time (TE) and the number of apnoeas exceeding 10 s. This analysis was performed using a computer program allowing recognition of the start and end of every inspiratory movement and apnoea. TI, TE and apnoeas were measured as indicated (fig. 1). The points recognized as the starts or ends of the inspiration and expiration were indicated by a mark on the hard copy of the breathing pattern, thus also allowing visual control. Artefacts due to moving, swallowing, speech and coughing were eliminated after reading of the hard copy by two independent observers. All respiratory movements during the study periods were analysed. The patients were not aware of the aims of the study or of the switch from air to O_2. For the purpose of the study, patients were dialysed in a separate, quiet room where they could listen to music and read magazines, whilst they remained seated in the same position.

Statistical analysis of differences between values obtained after the start and during HD (1 and 2 h) and between values obtained at 2 h of HD and during O_2 breathing, was performed using analysis of variance. If differences proved to be significant, Student's t-test was applied.

Table 1. – Gas exchange and ventilation during haemodialysis (CU-AT)

	0 min	60 min	120 min	160 min O_2 (6 $l \cdot min^{-1}$)
pH	7.34±0.03	7.33±0.02	7.34±0.03	7.34±0
Pao_2 kPa	12.3±1.2	10.3**±1.2	10.5**±1.8	26.3*±4.8
$Paco_2$ kPa	4.87±0.25	4.52±0.33	4.52*±0.28	4.47±0.27
$\dot{V}E$ $l \cdot min^{-1}$	6.8±1.9	5.6*±1.7	5.4*±1.3	5.4±0
f_R breaths·min^{-1}	18.4±4.6	15.9±3.9	15.7±2.9	15.0±2
VT ml	371±46	357±83	360±152	366±94
TI s	1.14±0.24	1.25±0.15	1.28±0.15	1.26±0
TE s	2.28±0.51	2.70±0.67	2.70±0.83	2.84±0
apnoeas >10 s per 10 min	0.0±0.0	0.4±0.2	1.4±0.6	0.2±0

Pao_2: arterial oxygen tension; $Paco_2$: arterial carbon dioxide tension; $\dot{V}E$: minute ventilation; f_R: respiratory frequency; VT: tidal volume; TI: inspiratory time; TE; expiratory time; CU-AT: cuprophane membrane and acetate-containing dialysate. Results are expressed as mean±SD. Number of subjects 5. *: significance *vs* time 0 (* $p<0.05$; ** $p<0.01$); +: significance *vs* time 120 min (+ $p<0.01$).

Results

Results of quantitative analysis of blood gases and breathing patterns during HD without O_2 breathing are given in table 1. The values for ventilation, TI and TE given at any time reflect the mean of the preceding period *i.e.* the previous 30 min at time 0, the previous 60 min at time 1 h and 2 h; pH values remained stable. Pao_2 decreased significantly ($p<0.01$ at 1 and 2 h). $Paco_2$ decreased slightly but significantly from 4.87±0.25 kPa (36.6±1.9 mmHg) at the start to 4.52±0.28 kPa (34.0±2.1 mmHg at 2 h ($p<0.05$). Minute ventilation also decreased significantly during the first 2 h of HD ($p<0.05$ at 1 and 2 h). Breathing frequency also decreased while tidal volume remained constant. There was a small although insignificant increase in TI, and TE also increased. The number of apnoeas exceeding 10 s increased markedly ($p<0.05$ at 2 h). Breathing remained irregular during the 10 min in which the patients were given air through a nasal cannula. The data obtained after O_2 administration are also given in table 1; pH was not influenced while Pao_2 increased significantly ($p<0.01$) and $Paco_2$ remained stable. Minute ventilation was not influenced by the administration of O_2 and breathing frequency, TI and TE remained constant. Tidal volume was nearly the same but the reduction in standard deviation suggests less breath-to-breath variation in tidal volume. Most remarkable was the significant decrease ($p<0.01$) in the number of apnoeas (fig. 2). After discontinuation of O_2 breathing this irregular breathing pattern reappeared.

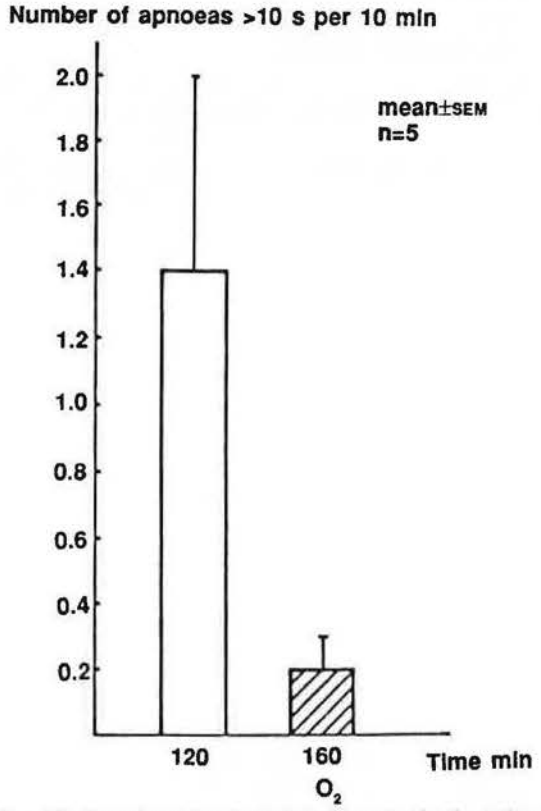

Fig. 2. – Number of apnoeas exceeding 10 s per 10 min during CU-AT haemodialysis. Effect of O_2 administration. CU-AT: cuprophane membrane and acetate-containing dialysate.

A typical breathing pattern during HD is depicted in figure 3. Variation in tidal volume and apnoeas exceeding 10 s occurred in addition to marked periodic breathing. As soon as O_2 was administered, ventilation became regular, the apnoeas disappeared and periodic breathing vanished completely (fig. 4).

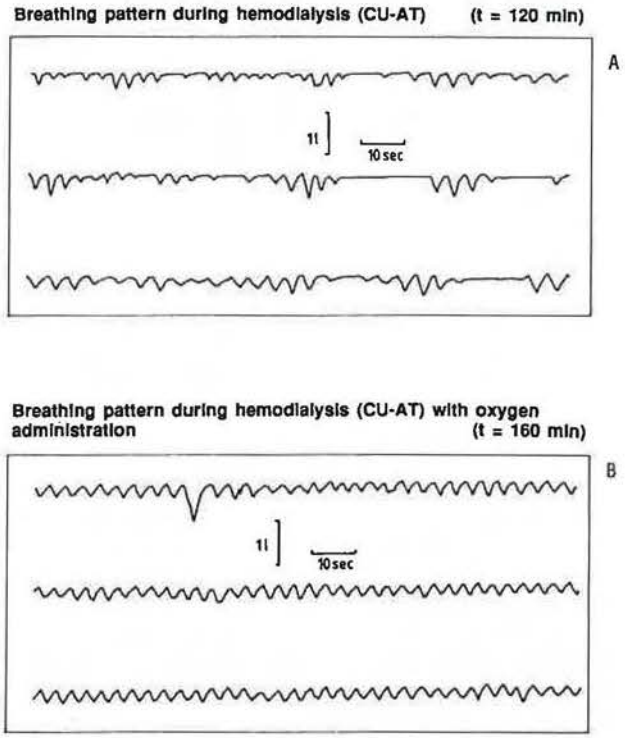

Fig. 3. – Breathing pattern (sum signal of ribcage and abdominal signals) during haemodialysis (CU-AT) at 120 min while the patient is breathing air (panel A) and at 160 min while he is breathing O_2 (panel B). O_2 was given *via* nasal prongs at a flow rate of 6 $l \cdot min^{-1}$. CU-AT: cuprophane membrane and acetate-containing dialysate.

Discussion

We have previously demonstrated that during HD with a bioincompatible membrane and acetate-containing dialysate allowing CO_2-loss, Pao_2 and $Paco_2$ decrease significantly. Minute ventilation decreases and the presence of a considerable number of apnoeas also leads to an increased TE [7, 10, 16]. We postulated that the decrease in ventilation was in part due to occurrence of the apnoeas and that the observed irregularities in breathing were due to the CO_2 unloading. CO_2 unloading in itself could have displaced minute ventilation toward the dog-leg part of the CO_2 response curve where CO_2 drive, if still present, remains almost constant. In the presence of (mild) hypoxia this would lead to an increased control of ventilation by the peripheral chemoreceptors. This hypothesis was also put forward to explain the irregularities in breathing occurring after induced voluntary hyperventilation [11].

The importance of hypoxia *per se* had already been suggested by our observation that, during HD with a biocompatible membrane in which no hypoxia occurs, hardly any change in breathing pattern had been observed [10]. We therefore wanted to strengthen this argument by studying the effect of silencing the peripheral chemoreceptors through administration of O_2 until Pao_2 exceeding 160 mmHg was reached, a value proposed as the "cut-off" point for arterial chemoreceptor activity in man [17]. In all patients in the study this turned the irregular breathing pattern into a regular one. Particular attention was given to the environment in order to avoid any important influence of acoustic or visual stimuli on the observed changes in breathing pattern. Since the methodological bias using nasal cannulae does not influence the breathing pattern [18, 19] the observed effect can be attributed to the O_2.

Minute ventilation was not decreased during O_2 administration. This means that peripheral chemoreceptors play a more important role in determining the regularity of breathing then in setting the level of ventilation. The simultaneous switch-off of peripheral and central chemoreceptors brought about by venous CO_2 unloading during hyperoxia does not affect mean ventilation in conscious humans. This offers a strong argument in favour of a non-chemical drive to breathing in humans, probably related to wakefulness ("awakening drive").

The effect on the breathing pattern could well be explained by the hypothesis of MILLER *et al.* [20]. They demonstrated that in hypoxic conditions the peripheral chemoreceptors react quickly to sudden changes in $Paco_2$, which are immediately reflected in the breathing pattern. The conditions during acetate and bioincompatible HD exactly fit these requirements. Since relieving the hypoxaemia necessarily eliminates the response to changes in $Paco_2$, this should also result in a regular breathing pattern.

Our initial hypothesis that the decrease in ventilation merely depends on the irregularities in breathing pattern seems to be weakened by these observations. We therefore believe that we have to reconsider the existence of slowly adapting venous CO_2 receptors as mentioned in previous work [7]. The slow decrease in minute ventilation observed during HD with acetate in all our observations could be explained by such an action of these receptors. It is striking that in all our experiments a small but significant decrease in $Paco_2$ of 3 or 4 kPa (2 or 3 mmHg) below the initial value is observed. This indicated that ventilation is controlled by stimuli other than $Paco_2$ alone, *e.g.* cortical reflexes related to wakefulness or mixed venous Pco_2 *via* pulmonary CO_2 receptors. In these conditions ventilation and $Paco_2$ are becoming less closely related than in the normo- or hypercapnic regions of the CO_2-response curve.

The question remains whether peripheral chemoreceptors play any role in the determination of the level of ventilation. After bilateral carotid body resection in chronic obstructive pulmonary disease (COPD) patients, ventilation decreases significantly with a decrease in Pao_2 and an increase in $Paco_2$ [21]. These patients underwent bilateral carotid body resection because of severe irreversible airflow limitation and incapacitating excessive dyspnoea. Whether this would also occur in non-obstructive patients remains to be determined. Our observations in this study indicate that peripheral chemoreceptors play a more important role in setting breathing rhythm than in adjusting the level of ventilation during conditions of absent or decreased CO_2 drive.

Although O_2 breathing could have improved cardiac output there is little indication that periodicity in breathing is dependent on the cardiac output [22]. Further evidence of the role of the peripheral chemoreceptors in determining the breathing pattern is found in other circumstances such as sleep and high altitude. In both conditions breathing pattern is again often found to be irregular.

During sleep the controlling role of the cortex is diminished leaving ventilation mediated by the chemical control systems [23, 24]. Hyperventilation brings the $Paco_2$ to the apnoeic threshold which is already shifted to the right by the sleep state. The controlling role of the peripheral chemoreceptors may then increase, leading to periodic breathing and sleep apnoea. Oxygen breathing decreases the number of apnoeas also, indicating that the carotid bodies may play a role [25].

At high altitude, lowlanders hyperventilate to compensate for the decrease in inspiratory Po_2 [26], and this hyperventilation induces hypocapnia. In this situation irregular breathing also occurs whilst O_2 breathing promptly improves the breathing pattern [27]. The importance of the peripheral chemoreceptors in the occurrence of the irregular breathing pattern is also stressed by the study of HACKETT *et al.* [28]. They showed that the irregularities even increased when almitrine, a peripheral chemoreceptor stimulant, was taken despite an increase in mean capillary O_2 saturation. In comparable hypoxic conditions at high altitude the occurrence of periodic breathing seems to be correlated with the degree of hypoxic sensitivity [29].

In conclusion, the present data provide further evidence for a major role of the peripheral chemoreceptors in the occurrence of irregular breathing in conditions of decreased or absent CO_2 drive. During CO_2 unloading the level of ventilation itself seems to be determined by other slowly adapting reflexes.

References

1. Eiser AR. – Pulmonary gas exchange during hemodialysis and peritoneal dialysis: interaction between respiration and metabolism. *Am J Kidney Dis*, 1985, 6, 131–142.
2. De Broe ME, Heyrman RM, De Backer WA, Verpooten GA, Vermeire PA. – Pathogenesis of dialysis induced hypoxemia: a short overview. *Kidney Int*, 1988, 33, S57–S61.
3. Craddock PR, Fehr J, Brigham KL, Kronenberg R, Jacob HS. – Complement and leucocyte-mediated pulmonary dysfunction in hemodialysis. *N Eng J Med*, 1977, 296, 769–774.
4. Hakim RM, Lowrie EG. – Hemodialysis associated neutropenia and hypoxemia: the effect of dialyzer membrane materials. *Nephron*, 1982, 32, 32–39.

5. Aurigemma NM, Feldman NT, Gottlieb M, Ingram RH Jr, Lazarus JM, Lowrie EG. – Arterial oxygenation during hemodialysis. *N Eng J Med*, 1977, 297, 871–873.
6. Romaldini H, Rodriguez-Roisin R, Lopez FA, Ziegler TW, Bencowitz HZ, Wagner PD. – The mechanisms of arterial hypoxemia during hemodialysis. *Am Rev Respir Dis*, 1984, 129, 780–784.
7. De Backer WA, Verpooten GA, Borgonjon DJ, Vermeire PA, Lins RR, De Broe ME. – Hypoxemia during hemodialysis: effects of different membranes and dialysate compositions. *Kidney Int*, 1983, 23, 738–743.
8. Cohn MA, Rao ASV, Broudy M, Birch S, Watson H, Atkins N, Davis B, Stott FD, Sachner MA. – The respiratory inductive plethysmograph: a new non-invasive monitor of respiration. *Bull Eur Physiopathol Respir*, 1982, 18, 643–658.
9. Sackner JD, Nixon AJ, Davis B, Atkins N, Sackner MA. – Non-invasive measurement of ventilation during exercise using a respiratory inductive plethysmograph. I. *Am Rev Respir Dis*, 1980, 122, 867–871.
10. De Backer WA, Heyrman RM, Wittesaele WM, Van Waeleghem JP, Vermeire PA, De Broe ME. – Ventilation and breathing patterns during hemodialysis induced carbon dioxide unloading. *Am Rev Respir Dis*, 1987, 136, 406–410.
11. Cunningham DJC, Robbins PA, Wolff CB. – Integration of respiratory responses to changes in alveolar partial pressures of CO_2 and O_2 and in arterial pH. *In:* Handbook of Physiology. Section 3: The respiratory system. vol II: Control of breathing, part 2. N.S. Cherniack and J.G. Widdicombe eds, American Physiological Society, Bethesda, Maryland, 1986, pp. 475–528.
12. Nielsen M, Smith H. – Studies on the regulation of respiration in acute hypoxia. *Acta Physiol Scand*, 1952, 24, 293–313.
13. Phillipson EA, Duffin J, Cooper JD. – Critical dependence of respiratory rhythmicity on metabolic CO_2 load. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1981, 50, 45–54.
14. Cunningham DJC. – Studies on arterial chemoreceptors in man. *J Physiol (Lond)*, 1987, 384, 1–26.
15. Stradling JR, Chadwick GA, Quirk C, Phillips T. – Respiratory inductance plethysmography: calibration techniques, their validation and the effects of posture. *Bull Eur Physiopathol Respir*, 1985, 21, 317–324.
16. De Backer W, Heyrman R, Wittesaele W, Van Waeleghem JP, De Broe ME, Vermeire PA. – Hypoventilation as a cause of hypoxemia during hemodialysis. *Bull Eur Physiopathol Respir*, 1986, 22, 88s.
17. Gardner WN. – The pattern of breathing following step changes of alveolar partial pressures of carbon dioxide and oxygen in man. *J Physiol (Lond)*, 1980, 300, 55–73.
18. Askanazi J, Silverberg PA, Foster RJ, Hyman AI, Milic-Emili J, Kinney JM. – Effects of respiratory apparatus on breathing pattern. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1980, 48, 577–580.
19. Perez W, Tobin MJ. – Separation of factors responsible for change in breathing pattern induced by instrumentation. *J Appl Physiol*, 1985, 59, 1515–1520.
20. Miller JP, Cunningham DJC, Lloyd BB, Young JM. – The transient respiratory effects in man of sudden changes in alveolar CO_2 in hypoxia and in high oxygen. *Respir Physiol*, 1974, 20, 17–31.
21. Vermeire P, De Backer W, Van Maele R, Bal J, Van Kerckhoven W. – Carotid body resection in patients with severe chronic airflow limitation. *Clin Respir Physiol*, 1987, 23, 165s–166s.
22. Lahiri S, Hsiao C, Zhang R, Mokashi A, Nishino T. – Peripheral chemoreceptor in respiratory oscillations. *J Appl Physiol*, 1985, 58, 1901–1908.
23. Berssenbrugge A, Dempsey J, Iber C, Skatrud J, Wilson P. – Mechanisms of hypoxia-induced periodic breathing during sleep in humans. *J Physiol (Lond)*, 1983, 343, 507–524.
24. Warner G, Skatrud J, Dempsey JA. – Effect of hypoxia-induced periodic breathing on upper airway obstruction during sleep. *J Appl Physiol*, 1987, 62, 2201–2211.
25. Gold A, Schwartz A, Bleecker E, Smith P. – The effect of chronic nocturnal oxygen administration upon sleep apnea. *Am Rev Respir Dis*, 1986, 134, 925–929.
26. West JB. – Man at extreme altitude. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1982, 52, 1393–1399.
27. Berssenbrugge A, Dempsey J, Skatrud J. – Hypoxic *versus* hypocapnic effects on periodic breathing during sleep. *In:* High altitude and men, J. West ed., American Physiological Society, Williams & Wilkins Baltimore, Maryland, 1984, pp. 115–127.
28. Hackett PH, Roach RC, Harrison GL, Schoene RB, Mills WJ Jr. – Respiratory stimulants and sleep periodic breathing at high altitude: almitrine *versus* acetazolamide. *Am Rev Respir Dis*, 1987, 135, 896–898.
29. Masuyama S, Kohchiyama S, Kunimoto F, Tojima Y, Kimura H, Kuriyama T, Honda Y. – Relationship between disordered breathing during sleep at high altitude and ventilatory chemosensitivities to hypoxia and hypercapnia. *Am Rev Respir Dis*, 1987, 135, A184.

Effet de l'administration d'oxygène sur le type respiratoire au cours de l'hémodialyse chez l'homme. R. M. Heyrman, W.A. De Backer, J.P. Van Waeleghem, M.J. Willemen, P.A. Vermeire, M.E. De Broe.

RÉSUMÉ: Au cours de l'hémodialyse (HD), qui entraîne une importante décharge de CO_2, l'on observe fréquemment un type respiratoire irrégulier. Ceci a été attribué à une diminution de l'activité des chémorécepteurs centraux et à une contribution accrue des chémorécepteurs périphériques dans la commande respiratoire chimique. Nous avons étudié 5 patients à un stade terminal d'insuffisance rénale, au cours de l'hémodialyse chronique, afin de confirmer ces observations. L'hémodialyse a été conduite avec une membrane cuprophane et un dialysat contenant de l'acétate. La ventilation a été mesurée de façon continue en utilisant la pléthysmographie d'inductance respiratoire. L'oxygène a été administré pendant 30 minutes au moyen de canules nasales à un débit de 6 $l \cdot min^{-1}$., commençant 130 minutes après la mise en route de l'hémodialyse. Les gaz du sang ont été prélevés à partir d'une ligne artérielle. Au cours de la période initiale sous respiration d'air, la Pao_2 a diminué de 12.3±1.2 kPa au temps 0, jusqu'a 10.5±1.7 kPa après 2 heures ($p<0.01$) (moyenne±DS). Tous les patients ont développé une respiration irrégulière avec 1.4±0.6 apnées de plus de 10 secondes par 10 minutes après 2 heures. La ventilation minute a diminué de 6.8±1.9 $l \cdot min^{-1}$. au temps 0, à 5.4±1.3 $l \cdot min^{-1}$. après 2 heures ($p<0.05$). Au cours de la respiration d'oxygène, la Pao_2 a augmenté jusqu'à 26.3±4.0 kPa ($p<0.01$) alors que la $Paco_2$ restait inchangée. Le type respiratoire irrégulier initialement observé a disparu complètement. Le nombre moyen d'apnées de plus de 10 secondes par 10 minutes a diminué jusqu'à 0.08±0.12 sous oxygène ($p<0.002$). Il n'y a pas eu d'autre modification significative du type respiratoire ni de la ventilation avant ou au cours de la respiration d'oxygène. Ces résultats suggèrent que les chémorécepteurs périphériques contribuent aux irrégularités respiratoires observées au cours de la décharge extra-corporéale de CO_2, puisqu'ils sont amortis lorsque l'administration d'oxygène entraîne une diminution rapide des apnées.

Eur Respir J., 1989, 2, 972–976