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Nocturnal hypoxaemia and quality of sleep in patients with chronic obstructive lung disease

WESLEY CORMICK, LESLIE G OLSON, MICHAEL J HENSLEY, NICHOLAS A SAUNDERS

From the Faculty of Medicine, University of Newcastle, and Department of Thoracic Medicine, Royal Newcastle Hospital, Newcastle, New South Wales, Australia

ABSTRACT Fifty patients with chronic obstructive lung disease were questioned about their sleep quality and their responses were compared with those of 40 similarly aged patients without symptomatic lung disease. Patients with chronic obstructive lung disease reported more difficulty in getting to sleep and staying asleep and more daytime sleepiness than the control group. More than twice as many patients (28%) as controls (10%) reported regular use of hypnotics. In a subgroup of 16 patients with chronic obstructive lung disease (mean FEV_1 0·88 (SD 0·44) l) sleep, breathing, and oxygenation were measured to examine the relationship between night time hypoxaemia and sleep quality. Sleep architecture was disturbed in most patients, arousals occurring from three to 46 times an hour (mean 15 (SD 14)/h). Arterial hypoxaemia during sleep was common and frequently severe. The mean (SD) arterial oxygen saturation (Sao_2) at the onset of sleep was 91% (7%). Nine patients spent at least 40% of cumulative sleeping time at an Sao_2 of less than 90% and six of these patients spent 90% of sleeping time below this level. Only four of 15 patients did not develop arterial desaturation during sleep. The mean minimum Sao_2 during episodes of desaturation was less in rapid eye movement (REM) sleep (72% (17%)) than in non-REM sleep (78% (10%); $p < 0·05$). The predominant breathing abnormality associated with desaturation was hypoventilation; only one patient had obstructive sleep apnoea. Arousals were related to oxygenation during sleep such that the poorer a patient's arterial oxygenation throughout the night the more disturbed his sleep (arousals/h *v* Sao_2 at or below which 40% of the total sleep time was spent: $r = 0·71$, $p < 0·01$). Hypoxaemia during sleep was related to waking values of Sao_2 and $Paco_2$ but not to other daytime measures of lung function.

It is well recognised that sleep is associated with arterial oxygen desaturation in patients with chronic obstructive lung disease.[1-6] Some physiological consequences of this desaturation, such as pulmonary hypertension, have been well investigated[2,7-9]; reports of the consequences of arterial hypoxaemia in terms of quality of sleep and sleep related symptoms, however, are few and conflicting.[10-14]

We report the perceptions of 50 patients with chronic obstructive lung disease of the quality of their sleep and compare these perceptions with those of a similarly aged population without lung disease but attending the outpatient department of a large urban hospital. In a subgroup of patients with chronic obstructive lung disease quality of sleep, as defined by electroencephalographic criteria, was compared with the degree of hypoxaemia experienced during sleep.

Address for reprint requests: Professor NA Saunders, Faculty of Medicine, David Maddison Clinical Sciences Building, Royal Newcastle Hospital, Newcastle, NSW, 2300 Australia.

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Methods

PATIENTS

Fifty consecutive patients with chronic bronchitis or emphysema, or both, who were attending the chest clinic of the Royal Newcastle Hospital were interviewed about their sleep habits. Patients with asthma were excluded from the study. Patients with chronic obstructive lung disease were taking regular inhaled β_2 agonists, inhaled beclomethasone, or oral theophylline preparations (or more than one of these). Forty control patients of similar age but

without symptomatic lung disease were interviewed during a routine attendance at the hospital's cardiology (n = 4), hypertension (n = 25), or dermatology (n = 11) clinic. Patients attending these clinics were taking various medications, including thiazide diuretics, β blockers, α methyldopa, clonidine, and peripheral vasodilators.

Sixteen of the patients with chronic obstructive lung disease gave consent for all night studies of breathing and oxygenation during sleep. Patients were in a stable clinical state at the time of study.

All patients gave informed written consent for the studies, which were approved by the Royal Newcastle Hospital ethics committee.

QUESTIONNAIRES

All patients completed a 22 item questionnaire, administered by an assistant, about their usual sleeping habits over the past six months. Patients did not know the interviewer. They were told that the purpose of the study was to investigate sleeping habits in patients attending the outpatient department. Questions related to initiation and maintenance of sleep (for example, perceptions of sleep latency and duration, frequency and causes of arousals, use of hypnotics and sedatives), events during sleep (for example, snoring, restlessness, dreaming) and sleep related daytime symptoms (for example, early morning headaches, daytime sleepiness, memory, concentration).

The test-retest reliability of the questionnaire was examined in 15 patients by readministration of the questionnaire two to six weeks after the initial interview. Concurrent validity of the questionnaire was assessed by interviewing the bed companions of 16 patients and seeking their response to items in the questionnaire about which they could be reasonably expected to have knowledge (for example, snoring, awakenings).

The 16 subjects undergoing sleep studies also completed a questionnaire relating to their perceptions of the preceding night's sleep.[15] This questionnaire was completed on the morning after the second sleep study, after one night's acclimatisation to the laboratory, and allowed comparison of the patient's perceptions with objective sleep recordings.

PULMONARY FUNCTION TESTING

All patients with chronic obstructive lung disease had spirometric measurements (FEV_1/FVC) made with a dry bellows spirometer (Vitalograph). In the 16 patients undergoing sleep studies total lung capacity and its subdivisions were measured plethysmographically. Arterial blood was sampled by radial artery puncture under local anaesthesia with the patient seated. Artery blood gas values were determined in duplicate by an automated method (Radiometer ABL-2). The ventilatory response to asphyxia was measured by the method of Hensley and Read,[16] and the ventilatory response to hypercapnia was measured by the rebreathing method of Read[17]; responses were measured at least in duplicate. Studies of pulmonary function were performed on a different day from the sleep studies.

SLEEP STUDIES

Patients were studied on two consecutive nights. They settled down to sleep at their usual time and were allowed to sleep through the night until they awoke spontaneously. No patient was taking hypnotics at the time of study. The first night was for acclimatisation and no data were analysed from this night. Sleep was monitored with silver cup electrodes secured by collodion in standard positions for electroencephalography, chin electromyography, and recording of eye movements by electro-oculography.[18] Arterial oxygen saturation (Sa_{O_2}) was monitored continuously by a Hewlett Packard 47201A ear oximeter.[19,20] Anteroposterior movement of the chest and abdomen was measured by two pairs of magnetometers (NP 1400Q) secured at the level of the nipples and umbilicus respectively. The magnetometers were not calibrated for volume and hence provided only a qualitative assessment of ventilation. Air flow at the nose and mouth was assessed with thermistors (Grass TCT-1R) taped securely to the face. Electrocardiographic monitoring was performed continuously.

All signals were recorded on a 12 channel ink pen recorder (Grass) at a paper speed of 5 mm/second.

ANALYSIS OF SLEEP STUDIES

Sleep was staged in 30 second epochs according to the criteria of Rechtschaffen and Kales.[18] Oxygenation was assessed by analysing cumulative time–Sa_{O_2} plots[21] to derive *(a)* the cumulative percentage time that the patient spent desaturated during sleep (% CT desat), desaturation being defined as a reduction in Sa_{O_2} of 4% or more below the stable baseline Sa_{O_2} at onset of sleep; *(b)* the percentage cumulative time spent with an Sa_{O_2} of 85%, 80%, 75%, 70%, and 65%; and *(c)* the Sa_{O_2} at cumulative percentage time of 90% (Sat_{CT90}) and 40% (Sat_{CT40}). Sat_{CT90} defined the Sa_{O_2} at or below which the patient spent 90% of the total sleep time (TST) and Sat_{CT40} defined the Sa_{O_2} at or below which the patient spent 40% TST.

Records were also analysed in terms of discrete episodes of desaturation to compare the present results with the results of previous studies. Each episode of desaturation, defined as a fall of 4% or more from the baseline sleeping Sa_{O_2}, was examined in terms of duration, minimum Sa_{O_2} reached, and breathing pat-

tern accompanying the fall in Sao_2. Breathing patterns were identified as episodes of apnoea of central, mixed and obstructive types; hypoventilation with or without snoring, characterised by decreased deflections of the thermistor and magnetometer tracings; and periodic breathing, characterised by cyclic variation in magnetometer and thermistor tracings.

STATISTICAL METHODS

Differences in questionnaire responses between patients with chronic obstructive lung disease and controls were compared by means of χ^2 analysis. For comparisons between test and retest results and between information given by patients and bed partners, kappa[22] and weighted kappa[23] scores were calculated as measures of agreement; the statistical significance of kappa was tested by Z score conversion. The significance of relationships within and between daytime and night time variables was assessed by Spearman rank correlation.

Results

PERCEPTION OF SLEEP QUALITY OVER PAST SIX MONTHS

Fifty patients (41 men, 9 women) with chronic obstructive lung disease were interviewed. Their mean (SD) age was 64 (9) years, FEV_1 0·81 (0·34) l, and FVC 1·95 (0·75) l. Of the 40 control subjects, 30 were men and 10 were women; their mean age was 63 (8) years.

Responses to 11 of the 22 questionnaire items are shown in table 1. The 11 items not shown were qualitative in nature (for example, "What usually awakens you at night?"). Patients with chronic obstructive lung disease reported more difficulty getting to sleep and staying asleep, more use of hypnotics, and more daytime sleepiness than the control subjects. No differences were seen between the groups in reported duration of sleep, prevalence of snoring or dreaming, early morning headache, or daytime concentration.

Test-retest reliability

Good agreement was found between first and second administration of the questionnaire. The kappa score for each of the 22 items was positive, indicating agreement between the first and second occasion of testing. The degree of agreement (range 0·11–1·00) was greater than could be expected by chance alone ($p \leqslant 0·05$) on 12 of the 22 items.

Concurrent validity of the questionnaire

Agreement was found between the 16 pairs of reports by patients and bed companions on the patient's sleeping habits for the six questionnaire items so tested. Kappa scores ranged from +0·18 to +1·00 and on four of the six items this agreement was significant ($p \leqslant 0·05$).

SLEEP STUDIES

Patient characteristics

The general characteristics of the 16 patients studied during sleep are shown in table 2. The patients' ages ranged from 48 to 84 years and all but one were men. Fifteen of the 16 were current cigarette smokers (n = 4) or ex-smokers. Six patients had hypercapnia ($Paco_2$ > 45 mm Hg (6 kPa)) and seven had hypoxaemia (Pao_2 < 60 mm Hg (8 kPa)) while awake. The ventilatory responsiveness to asphyxia ranged from 0·10 to 1·8 l $min^{-1}\%Sao_2^{-1}$ and ventilatory response to hypercapnia ranged from 0·02 to 1·70 l min^{-1} $mm\,Hg^{-1}$.

Characteristics of sleep

Only results from the second study night are reported (table 3, fig 1). The control values shown in figure 1 were not obtained in the present study but were taken from work done by others in different environ-

Table 1 *Responses to the principal items in the questionnaire*

Item		No (%) of Patients (n = 50)	No (%) of Controls (n = 40)	χ^2	p
Q1	Trouble falling asleep	18 (36)	6 (15)	5·01	< 0·05
Q2	Use of hypnotics regularly	14 (28)	4 (10)	4·50	< 0·05
Q3	Fall asleep within minutes of lights out	19 (38)	25 (63)	5·78	< 0·025
Q4	Duration of sleep < 6 hours	20 (40)	12 (30)	0·97	NS
Q5	Snoring	24 (59)*	22 (63)*	0·66	NS
Q9	Restlessness	21 (42)	7 (23)	7·78	< 0·01
Q10	Dreaming infrequent	26 (52)	13 (33)	3·61	NS
Q12	Awakenings > 2/night	38 (76)	21 (53)	5·43	< 0·025
Q16	Daytime sleepiness	36 (72)	12 (30)	15·75	< 0·001
Q19	Early morning headaches	14 (28)	5 (13)	3·21	NS
Q21	Impaired daytime concentration	16 (32)	11 (28)	0·21	NS

*Nine patients and five controls did not know whether they snored.

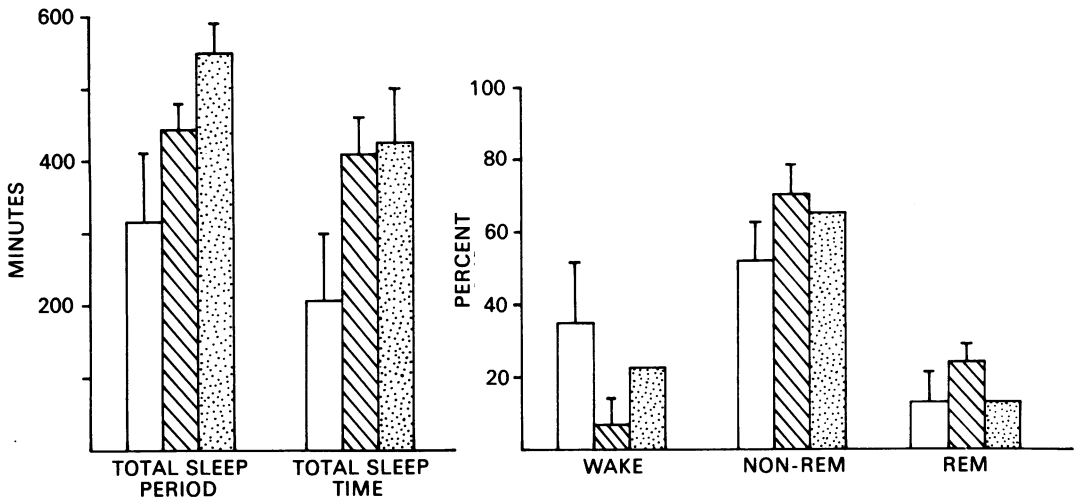

Fig 1 *Duration of sleep (left panel) and proportions of rapid eye movement (REM) and non-REM sleep and of wakefulness as percentages of total sleep period (right panel) in patients with chronic obstructive lung disease (open bars) and in two control groups of similar age previously reported by others. Controls reported by Williams et al[29] (hatched bars) did not have respiration monitored during sleep whereas controls reported by Carskadon et al[27] (stippled bars) had monitoring similar to that of our study group. Patients with chronic obstructive lung disease had a shorter sleep period and more intervening wakefulness than controls.*

ments.[24 25] The wide range of values of total sleep period (TSP) among patients in the present study despite approximately equal total study duration indicates that some patients had great difficulty falling asleep whereas others fell asleep easily. The percentage of REM sleep varied from zero to 30·4% TSP but on average the REM sleep period was about 20% of the time spent asleep. Sleep architecture was disturbed in most patients; the number of sleep state changes ranged from 7 to 54 per hour TST and arousals to wakefulness from 3 to 46 per hour TST.

Table 2 *Characteristics of the 16 patients with chronic obstructive lung disease taking part in sleep studies*

	Mean	*SD*
Age (y)	64·8	9·7
FEV_1 (l)	0·88	0·44
FVC (l)	2·06	0·77
TLC (% predicted)	117	24
RV (% predicted)	197	64
$\%Sa_{O_2}$	89	7
Pa_{O_2} (mm Hg)	64	17
Pa_{CO_2} (mm Hg)	43	8
$\Delta\dot{V}_I/\Delta Sa_{O_2}$ ($l\,min^{-1}\,\%Sa_{O_2}^{-1}$)	0·65	0·61
$\Delta\dot{V}_I/\Delta Pa_{CO_2}$ ($l\,min^{-1}\,mm\,Hg^{-1}$)	0·61	0·62

FVC—forced vital capacity; TLC—total lung capacity; RV—residual volume; $\%Sa_{O_2}$—% arterial oxygen saturation (calculated); Pa_{O_2}—arterial oxygen tension; Pa_{CO_2}—arterial carbon dioxide tension; $\Delta\dot{V}_I/\Delta Sa_{O_2}$—ventilatory response to asphyxia; $\Delta\dot{V}_I/\Delta Pa_{CO_2}$—ventilatory response to hypercapnia.
Conversion: Traditional to SI units—Blood gas tensions: 1 mm Hg ≈ 0·133 kPa.

Relation between perceived quality of sleep and electroencephalogram

No significant differences were observed between patients' perceptions and objective measures of sleep latency (mean (SD) 19 (15) *v* 30 (11) min), total sleep period (283 (111) *v* 316 (95) min), or number of arousals lasting longer than five minutes (3·2 (1·9) *v* 5·3 (3·1), Wilcoxon matched pairs test). When all EEG records of arousals were included in the analysis (table 3), subjective and objective reports differed significantly ($p < 0·01$).

Oxygenation during sleep

Table 4 shows the severity of arterial oxygen desaturation during the second night of study. Oximetry data were not available for one patient owing to malfunctioning of the equipment. Four patients did not develop desaturation during sleep; these patients had awake baseline Sa_{O_2} levels of 95%, 95%, 95%, and 90%. The remaining 11 patients spent 4–98% of sleeping time with an Sa_{O_2} more than 4% less than the baseline level ($\%CT_{desat}$). Nine patients spent 40% of their sleeping time with an Sa_{O_2} below 90% (Sat_{CT40}) and six patients spent 90% of their sleeping time below this level (Sat_{CT90}). As a group, patients spent 31·2% (42·3%) TST (mean (SD)) at or below 85% Sa_{O_2}, 26·1% (39·9%) TST at or below 80% Sa_{O_2}, 19·0% (34·6%) TST at or below 75% Sa_{O_2}, 15·4% (32·0%) TST at or below 70% Sa_{O_2}, and 12·7% (29·0%) TST at or below 65% Sa_{O_2}. The large

Table 3 *Characteristics of the sleep of 16 patients with chronic obstructive lung disease*

Sleep variable	*Mean (SD) Range*	
TSP (min)	316 (95)	135–461
TST (min)	208 (88)	50–323
Wakefulness (%*)	35 (19)	13–65
Non-REM sleep (%*)	52 (14)	30–73
REM sleep (%*)	13 (9)	0–30
Sleep state change/h TST	17 (12)	7–54
Total No of arousals (> 15 seconds)	37 (25)	15–103
No of arousals/h TST	15 (14)	3–46
Mean duration of uninterrupted sleep periods (min)	8 (5)	1·3–18

TSP—total sleep period, from onset of sleep to last awakening, including time spent in all intervening awakenings; TST—total sleep time (total sleep period minus intervening wakefulness); REM—rapid eye movement.
*Percentage of total sleep period.

Table 4 *Oxygenation during sleep* in 15 patients with chronic obstructive lung disease*

	Mean (SD) Range	
Continuous data		
$\%Sa_{O_2}$ baseline (sleep onset)	90·9 (7·1)	70–97
Sat_{CT90}	86·9 (11·0)	52–95
Sat_{CT40}	83·6 (12·1)	50*–94
$\%CT_{desat}$	36·5 (33·6)	0–98
Episodes of arterial desaturation†		
No/h total sleep period	8·9 (11·6)	0·3–39·5
Mean minimum $\%Sa_{O_2}$	75·6 (10·7)	56–89
Duration (seconds)	42·1 (33·6)	9–111

*Oximetry data not available on one patient owing to malfunction of equipment. Continuous data values derived from cumulative time/$\%Sa_{O_2}$ plots.
†Episode of arterial desaturation defined as ≥4% fall in Sa_{O_2} from sleep onset baseline $\%Sa_{O_2}$; values refer only to those patients (11–15) who had episodes of desaturation.
‡Values < 50% Sa_{O_2} scored as 50%.
Sa_{O_2}—arterial oxygen saturation; Sat_{CT90}—Sa_{O_2} at or below which the patient spent 90% of total sleep time; Sat_{CT40}—Sa_{O_2} at or below which the patient spent 40% of total sleep time; $\%CT_{desat}$—% of patient's cumulative time asleep spent at an Sa_{O_2} ≥4% less than baseline $\%Sa_{O_2}$ at the onset of sleep.

The large standard deviations show that the cumulative time spent at any given Sa_{O_2} varied widely among patients. Indeed, nine patients did not spend any of their sleeping time at an Sa_{O_2} less than 80%.

Three of the 16 patients had multiple episodes of apnoea of more than 10 seconds' duration during sleep but in only one were the criteria of sleep apnoea achieved.[26] Apnoea in this patient occurred almost exclusively in REM sleep. The three patients in whom apnoeas were observed were all snorers and all their episodes of apnoea were obstructive in type. Most of the episodes of worsening hypoxaemia observed in the 11 patients who developed desturation were associated with hypoventilation, with or without snoring. One patient's dominant breathing pattern was cyclical ventilation. In the 11 patients who developed desaturation during sleep arterial oxygenation was worse during REM sleep than during non-REM sleep (mean (SD) minimum Sa_{O_2} during episodes of desaturation (Sa_{O_2} 72·3% (17·0%) *v* 78·2% (10·2%); $p < 0·05$, paired Student's *t* test.

RELATIONSHIP BETWEEN WAKING PULMONARY FUNCTION AND SLEEPING HYPOXAEMIA

No relationship was found between nocturnal hypoxaemia and severity of lung disease (as judged by spirometry and lung volumes) or ventilatory responsiveness. A relationship was found, however, between waking Sa_{O_2} and sleeping hypoxaemia, whether this was expressed as a continuously distributed variable, Sat_{CT40} ($r = 0·85$, $p < 0·01$) or as mean minimum Sa_{O_2} during episodes of desaturation ($r = 0·82$, $p < 0·01$)—fig 2). An inverse relationship existed between

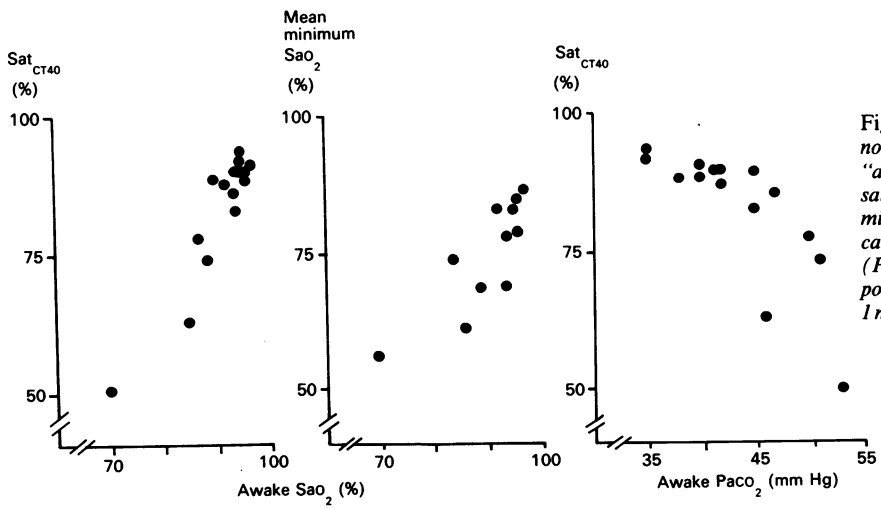

Fig 2 *Relation between nocturnal hypoxaemia and "awake" arterial oxygen saturation (Sa_{O_2}—left and middle panels) and arterial carbon dioxide tension (Pa_{CO_2}—right panel). Each point represents one patient. 1 mm Hg ≈ 0·133 kPa.*

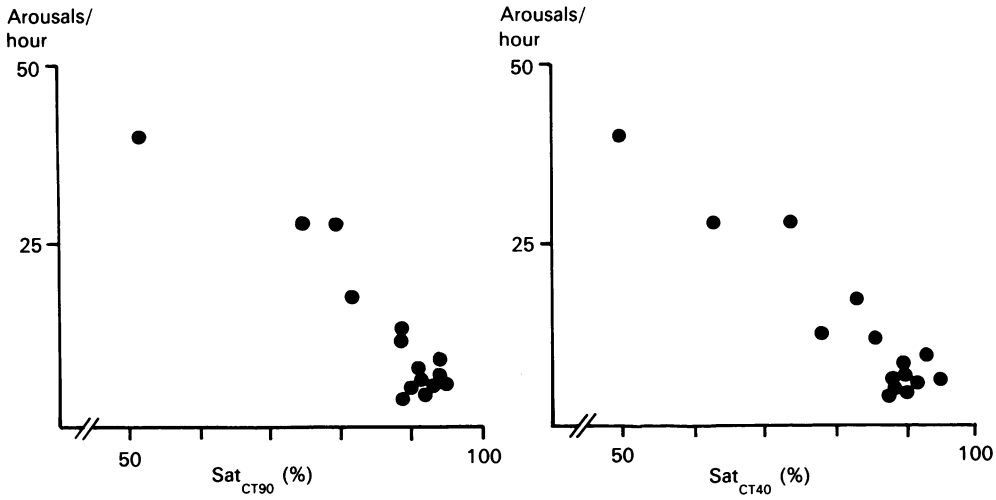

Fig 3 *Relation between arousals from sleep and nocturnal hypoxaemia expressed as saturation at cumulative time 90% (Sat_{CT90}—left panel) and saturation at cumulative time 40% (Sat_{CT40}—right panel) (see under "Methods").*

waking $PaCO_2$ and sleeping oxygenation ($p < 0{\cdot}01$). Thus those patients with a lower SaO_2 and a higher $PaCO_2$ when awake spent their sleeping time at a lower level of arterial oxygenation and had greater arterial hypoxaemia during episodes of disordered breathing.

RELATIONSHIP BETWEEN AROUSALS AND NOCTURNAL HYPOXAEMIA

The relationship between arousals and nocturnal hypoxaemia was examined in two ways. Firstly, the number of arousals/hour TST was related to $\%CT_{desat}$, Sat_{CT90}, Sat_{CT40}, number of episodes of desaturation/hour TSP, and mean minimum SaO_2 during desaturation. Arousals were related inversely to Sat_{CT90} ($r = 0{\cdot}63$, $p < 0{\cdot}05$) and Sat_{CT40} ($r = 0{\cdot}71$, $p < 0{\cdot}01$) (fig 3) but not to the other variables. Secondly, the relationship between intervening wakefulness and number of hypoxaemic episodes was examined; no significant relationship was found (fig 4). Thus, while arousals were related to overall oxygenation during sleep such that those with the lowest arterial oxygenation had the most frequent arousals, no relationship existed between arousals (or intervening wakefulness) and discrete episodes of desaturation.

Relationship between sleeping hypoxaemia and perception of sleep

In the 16 patients who underwent sleep studies, questionnaire responses were related to measurements of severity of hypoxaemia during sleep, χ^2 analysis being performed after patients had been assigned to two groups according to the median values of $\%CT_{desat}$, Sat_{CT90}, Sat_{CT40}, number of episodes of desaturation/hour TST, and mean minimum % SaO_2 during desaturation. No significant relationships were observed.

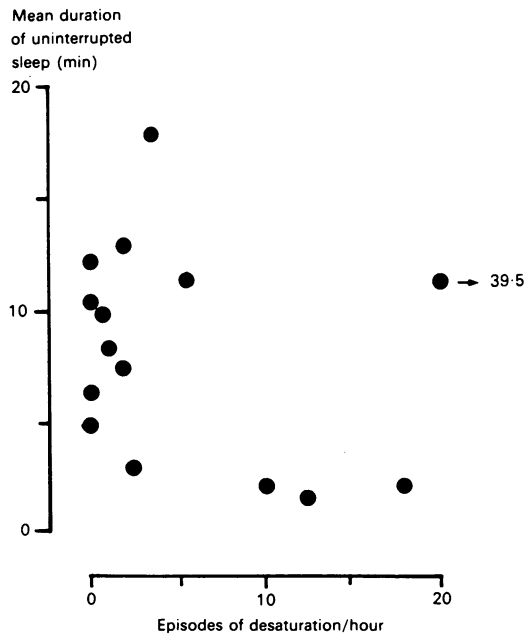

Fig 4 *Relation between mean duration of episodes of uninterrupted sleep and discrete episodes of arterial desaturation ($SaO_2 \geq 4\%$ less than baseline SaO_2). Each point is one subject.*

Discussion

The results of this study show that patients with chronic obstructive lung disease report poorer quality sleep than other patients of similar age attending a large urban outpatient department. In patients with chronic obstructive lung disease nocturnal hypoxaemia is common and frequently severe, and is related to arousal from sleep. Hypoxaemia during sleep is most severe in those patients with lower Sa_{O_2} and higher Pa_{CO_2} while awake during the day, but it is not related to other routine measures of daytime pulmonary function. It does not appear possible to predict those at risk of severe arterial desaturation during sleep from patients' own reports of sleep related symptoms.

There are problems associated with the use of questionnaires to examine sleeping habits. Most studies reporting perceptions of sleep have not provided information relevant to the validity or reliability of the questionnaire. The questionnaire used in the present study had acceptable test-retest reliability and there was good agreement between patients and bed partners on the limited number of items so tested. Too much emphasis should not, however, be placed on this latter point since some of the patient's information about sleeping habits almost certainly came from the bed partner (for example, snoring). Comparison of immediate perceptions of sleep quality with objective variables defined by EEG showed that our patients' perceptions were reasonably accurate when considered as a group. This finding supports the results of Johns,[27] who studied sleep latency in normal subjects. He found no difference between group mean values of sleep latency derived from objective measurements (that is, EEG) and from subjective reports of the night's sleep. Johns[27] also showed a significant correlation between objective measurements of sleep latency in the laboratory and habitual sleep latency at home as reported by questionnaire.

Our choice of control subjects can be criticised on several grounds. Although free from breathlessness, control subjects may have had mild left ventricular failure and others were taking antihypertensive medication that is known to cause sedation. Moreover, drugs taken by the patients with chronic obstructive lung disease may have interfered with their sleep. These drawbacks are unlikely to negate our findings. The possible inclusion of controls with left ventricular failure should have minimised the possibility of finding differences in sleep behaviour between patients with lung disease and controls. Patients with chronic obstructive lung disease were sleepier during the day than controls, despite the use of potentially sedating antihypertensive medication by some controls. Miles and Dement[28] have recently reviewed studies of the perception of sleep in elderly people. Sleep complaints are frequent in this population, the most consistent finding being an increased number of night time awakenings. Other complaints reported frequently by the elderly include difficulty in falling asleep, increased use of hypnotics, increased early morning waking, and decreased daytime function. The perception of sleep by our control subjects is very similar. The greater prevalence of difficulty in getting to sleep, restlessness with more frequent awakenings, and daytime sleepiness in patients with chronic obstructive lung disease cannot be attributed to age alone.

Laboratory studies support the perceptions of the elderly that their sleep is more disturbed than the sleep of younger groups of people. Total sleep time and slow wave sleep decrease with age and arousals are more frequent throughout the night.[28,29] Sleep appears to be even more disturbed in patients with chronic obstructive lung disease.[10-12] Our findings are in general agreement with these studies, although our patients had more intervening wakefulness and less non-REM sleep than previously reported. These objective data from several centres mirror the patients' perceptions reported here that sleep is difficult to initiate and maintain.

The cause of disturbed sleep in patients with chronic obstructive lung disease remains unclear and is likely to be multifactorial. We have shown an association between arousals and severity of sleeping hypoxaemia. This finding is at variance with the results of Calverley and coworkers[11] but supports the findings of Fleetham and coworkers,[10] who showed a statistical association between arousals and episodes of desaturation. The picture is far from clear, however. Calverley and coworkers[11] found that patients with the greatest number of episodes of hypoxaemia had the *least* intervening wakefulness but showed that oxygen administration improved sleep, which is in agreement with the findings of Kearley and associates.[13] By contrast, although Fleetham and coworkers[10] found an association between episodes of hypoxaemia and arousals, they found no effect of oxygen administration on sleep and a more recent study confirms this, although there was a trend towards longer sleep time with oxygen treatment.[14] Comparisons between studies are made difficult by differences in the way hypoxaemia during sleep is expressed.[30] We found an association between arousals and hypoxaemia only when Sa_{O_2} was expressed as a continuous variable. We emphasise that we have not established a causal relationship between hypoxaemia and sleep fragmentation in our patients. Indeed, review of individual records showed that some patients had multiple arousals with minimal

desaturation through the night, whereas others repeatedly developed desaturation without much sleep disturbance. Possibly, as chronic obstructive lung disease progresses and daytime hypoxaemia becomes more severe, the relationship between hypoxaemia and sleep fragmentation changes. Perhaps recurrent hypoxaemic episodes during sleep blunt arousal mechanisms. Thus late in their disease some patients with considerable nocturnal hypoxaemia may sleep better and have fewer arousals than at an earlier stage of their disease. Long term studies are needed to show whether oxygen administration will substantially improve the subjective and objective quality of sleep in patients with chronic obstructive lung disease and to test the hypothesis[30] that blunted arousal mechanisms may play an important part in the development and progression of chronic respiratory failure.

The finding of an association between waking Sa_{O_2} and Pa_{CO_2} and sleeping hypoxaemia supports the findings of others.[1 4 6 31] These relationships are not unexpected given the known effects of sleep on breathing and the shapes of the alveolar ventilation–Pa_{CO_2} and oxyhaemoglobin dissociation curves. The lack of association between ventilatory responsiveness to chemical stimuli and sleeping hypoxaemia reported in the present study contrasts with the findings of studies that have reported an association between a low waking chemical drive to breathing and night time hypoxaemia.[4 32] The lack of relationship in the present study may be due to our small sample size in the face of known variability in responsiveness.

We conclude that patients with chronic obstructive lung disease have more sleep related symptoms and more disturbed sleep than a similarly aged population without lung disease. Arousals from sleep are associated with severity of hypoxaemia, but whether oxygen treatment would improve quality of sleep, objectively and subjectively, remains to be determined.

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