Eur Respir J
1991, 4, 655–659

# Quantification of sleep disordered breathing by computerized analysis of oximetry, heart rate and snoring

H. Rauscher, W. Popp, H. Zwick

*Quantification of sleep disordered breathing by computerized analysis of oximetry, heart rate and snoring. H. Rauscher, W. Popp, H. Zwick.*

**ABSTRACT: Intermittent snoring and cyclic oscillations of heart rate and oxyhaemoglobin saturation ($Sao_2$) are characteristic features of the obstructive sleep apnoea syndrome (OSAS). Thus, overnight recordings of laryngeal sounds and heart rate by a portable device (MESAM) and of $Sao_2$ by oximetry are applicable to screen outpatients for the presence of OSAS. Computerized analysis for time intervals of constant heart rate and intervals between snoring sounds is used by MESAM to quantify respiratory disturbances during sleep. Rapid increases in $Sao_2$ during the postapnoeic hyperventilation period together with the number of desaturations are used by a new software for quantitative analysis of oximetry. To elucidate reliability of results from automatically scored MESAM and oximetry recordings, we compared the four computer calculated respiratory disturbance indices from heart rate (RDIH), snoring (RDIS), resaturations (RDIR) and desaturations (RDID) with the apnoea plus hypopnoea index (AHI) from simultaneously peformed polysomnography. The study population consisted of 53 snorers with an AHI of 19.0±2.6 (median±SEM; range 0.7–87.8). Whereas both RDI's from MESAM correlated rather weakly with the AHI from polysomnography (RDIH: r = 0.32, p<0.05; RDIS: r = 0.33, p<0.05), this correlation was much better for the RDI's from oximetry (RDIR: r = 0.951, RDID: r = 0.93; p<<0.0001). Accepting a plus/minus 30 percent difference from the AHI, the RDIR classified 77% of patients correctly, the RDID 62%, the RDIS 32% and the RDIH 23%. In conclusion, results from computerized analysis of oximetry for desaturations and rapid resaturations correlate more closely with polysomnography than those from automatic scoring of MESAM recordings.**

*Eur Respir J, 1991, 4, 655–659*

Correspondence: H. Rauscher, Pulmonary Department, Krankenhaus Lainz, Wolkersbergenstr. 1, A-1130 Vienna, Austria.

Keywords: Breath sounds; pulse oximetry; oxygen desaturation; screening; sleep apnoea; snoring.

Received: August 21, 1990; accepted after revision January 23, 1991.

The obstructive sleep apnoea syndrome (OSAS) causes increased morbidity and mortality [1–6], mainly from cardiovascular diseases and accidents [7, 8]. Thus, early detection of OSAS is mandatory but difficult because of the lack of specific symptoms in early stages of the disease [9]. Since it is neither possible nor appropriate to do sleep studies by polysomnography in everyone who snores or reports vague symptoms suggestive of sleep apnoea, reliable screening methods for OSAS are needed.

Recurrent apnoeas during sleep are associated with intermittent snoring and cyclic oscillations of heart rate and of oxyhaemoglobin saturation ($Sao_2$). Hence, tracheal sound recordings by microphones [10, 11], recordings of $Sao_2$ by oximetry [12], and long-term registrations of heart rate from an electrocardiograph (ECG) [11, 13] are the most common screening methods for OSAS. Each of these methods is usually conclusive about the presence or absence of OSAS. However, quantification of nocturnal respiratory disturbances is desirable as a baseline for follow-up studies in snorers with mild sleep disordered breathing, who are at risk to develop OSAS. To avoid time consuming manual scoring of the recordings [14, 15], several computer software systems for automatic analysis have been developed.

Constancy of heart rate and intervals between snoring sounds are used by MESAM (Madaus Electronics Sleep Apnoea Monitor) for quantification of respiratory disturbances during sleep [11]. Computerized analysis of oximetry is usually done by searching for desaturations [16]. However, due to the shape of the oxyhaemoglobin dissociation curve, apnoeas and hypopnoeas during sleep do not invariably cause significant falls in $Sao_2$ [17, 18]. Thus, computerized search for desaturations frequently misses apnoeas starting from high baseline $Sao_2$ as well as hypopnoeas with less pronounced desaturations. Since resumption of breathing after apnoeas or hypopnoeas is associated with a period of compensatory hyperventilation [19] causing a rapid and mostly overshooting increase in $Sao_2$,

computerized search for rapid resaturations is very sensitive to detect respiratory events during sleep [20]. Hence, we developed a new software which calculates the number of rapid resaturations as well as desaturations.

To clarify the value of quantitative analysis of sleep studies by this software and by MESAM for clinical routine, we compared computer calculated results of the two systems to manually scored results from simultaneously done polysomnography.

## Methods

Oximetry for computerized analysis with our software was done by a Minolta Pulsox 7 using the finger-sensor. The Minolta Pulsox 7 calculates every second the arithmetic mean of the $Sao_2$ values for the preceding seven. Thus, a file of every second actualized mean values is created, and every fifth of these values is put into the memory and stored overnight within the device. The next morning, data are transmitted to a personal computer. Our programme searches for rapid resaturations (RES), defined as increases in $Sao_2$ of 3% or more within 10 s, and for desaturations (DESAT), defined as decreases in $Sao_2$ of 4% or more within 40 s. To avoid multiple counting of RES and DESAT with very large changes in $Sao_2$, the software contains time limits for omission of data following an increase or decrease in $Sao_2$ fulfilling the criteria to be recognized as an event. Accordingly, the programme starts to search for RES from the highest value of the 15 s following the preceding RES, which should represent the end of the arousal related hyperventilation period. By analogy, the search for DESAT starts from the lowest value of the 30 s following the preceding DESAT, which should mark the end of apnoea or hypopnoea. Since the majority of apnoeas last for 15–50 s, omitting the values measured between an event found and these starting points provides high specificity without loosing much sensitivity.

Two respiratory disturbance indices (RDI) are calculated from the oximetry data: the RDIR, defined as the number of RES per hour of observation, and the RDID, defined as the number of DESAT per hour of observation. For this study, observation time was set to 4 h (0.00 to 4.00 a.m.) in all of the patients.

MESAM monitors heart rate by measuring the R-R intervals from a single-lead ECG. Snoring is monitored by a subminiature microphone above the larynx. The information 'snoring' is scored if the relative power of frequencies between 50–800 cycles per second exceeds 50% of the total power. Furthermore, 'loud snoring' is scored if the output of the microphone is above a predefined threshold (1.1 mV at 1000 $cycles \cdot s^{-1}$). All three of these informations, *i.e.* heart rate, snoring and loudness, are sampled with a frequency of 1 per second and stored overnight within the recording device. Data are read out by a personal computer the next morning and analysed by the MESAM-software.

MESAM calculates a RDI from the periods of constant heart rate (RDIH) between 11–60 s. This is done by transforming the instantaneous heart rate to a percentage value of the mean heart rate for the last 5 min. All values between 90% and 109% are scored as 100% to omit variations of heart rate not exceeding plus/minus 10%. MESAM calculates a RDI from the snoring intervals between 11–60 s (RDIS). As for oximetry, these parameters were calculated for the time between 0.00 and 4.00 a.m.

Oximetry and MESAM recordings were done during a full night polysomnographical examination including continuous registration of electroencephalogram (EEG), electro-oculogram (EOG), submental electromyogram (EMG), ECG, air flow at nose and mouth (thermistors), movements of rib cage and abdomen (Respitrace, Ambulatory monitoring, Ardsley, NY) and $Sao_2$ from the ear. For polysomnography, we used a different model oximeter (Novametrix 505) with a shorter interval for averaging primary data (2 s) to control for the rather long averaging period (7 s) of the Minolta Pulsox 7. Sleep staging was done according to standard criteria [21]. Apnoeas were defined as cessation of airflow at nose and mouth for longer than 10 s. Hypopnoeas were defined as a more than 50% reduction in the sum signal of rib cage and abdominal movements compared to the preceding 5 breaths for longer than 10 s, accompanied by a fall in $Sao_2$ to 92% or lower if baseline was equal or above 94% or a fall in $Sao_2$ of 3% or more if baseline was 93% or lower.

The sum of all apnoeas and hypopnoeas per hour of sleep represented the apnoea plus hypopnoea index (AHI). Two AHI's were calculated from polysomnography: the first for the real time asleep and the second for the 4 h used for the automatically calculated indices. The latter was used for correlations between the computer methods and polysomnography to avoid possible error due to uneven distribution of events over the night. The AHI for the whole night was used for comparisons between the computer calculated RDI's and polysomnography. The reason for this was, that both computer methods are intended to be used as screening methods and in screening outpatients the real time asleep is not known. Thus, calculations have to be done for an arbitrary period, but the results for this period should still reflect the AHI for the whole night.

Results are given as medians and standard error of the median (SEM) except where otherwise indicated. Correlations between computer-found events and polysomnography were calculated by Spearman's rank correlation. Comparisons between groups were done by the chi-square-test. A p-value below 0.05 was considered as statistically significant.

### *Patients*

We studied 53 snorers presenting with symptoms suggestive of OSAS. Mean age of the study population was 50.2±9.9 yrs (m±SD), mean Broca-Index (= weight in kg × 100/height in cm - 100) was 117.2±2.6 (range 82–226). During the study night, the patients slept for

6.6±1.0 (mean±SD) h and had a mean $Sao_2$ asleep of 93.5±0.2 % (range 78.9–96.8). Awake $Sao_2$ in the supine position was above or equal to 95% in all of the patients. The patients' minimum $Sao_2$ during the night was 81.2±1.2% (range 36–93) and the mean of the 30 lowest $Sao_2$ values observed was 87.3±1.1% (range 42.4–95.4).

Heart rate was 72.4±3.8 beats per minute in the awake supine subjects resting for 5 min, and 67.6±2.8 during sleep. None of the patients were on medication influencing heart rate, like β-adrenergic antagonists, and all patients showed sinus rhythm on ECG while awake.

## Results

Manual scoring of polysomnography revealed 7.5±2.8 apnoeas per hour of sleep with a range from 0.2–85.7. The sum of all apnoeas and hypopnoeas per hour of sleep (AHI) was 19.0±2.6 (range: 0.7–87.8) for the whole night and 21.2±3.1 for the period between 0.00 and 4.00 a.m.

Correlations of the computer calculated RDI's from oximetry with the AHI for the same period of time from polysomnography are given in figure 1. Using Spearman's rank test a highly significant correlation ($p<0.0001$) was found for both RDI's, Spearman's r being 0.951 for the RDIR and 0.93 for the RDID.

Figure 2 shows the correlations of the computer calculated RDI's from MESAM with the AHI. The rank correlation coefficient was 0.316 for the RDIH ($p<0.05$) and 0.329 for the RDIS ($p<0.05$).

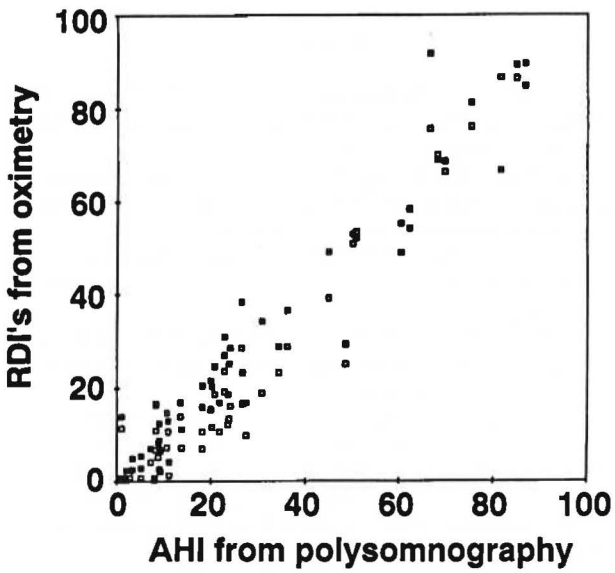


Fig. 1. – Correlations of the respiratory disturbance index (RDI) from resaturations (RDIR: ■) and desaturations (RDID: □) with the apnoea plus hypopnoea index (AHI) from simultaneously done polysomnography (n=53); Spearman's rank correlation coefficient=0.951 for RDIR ($p<0.0001$) and 0.93 for RDID ($p<0.0001$).

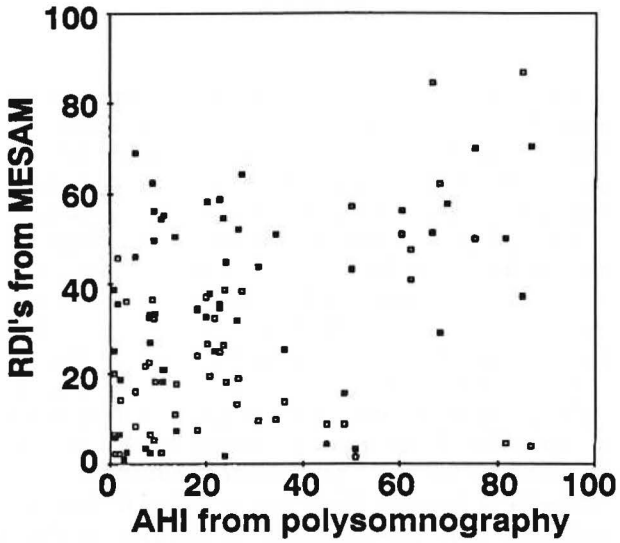


Fig. 2. – Correlations of the respiratory disturbance index (RDI) from constancy of heart rate (RDIH:■) and snoring intervals (RDIS:□) with the apnoea plus hypopnoea index (AHI) from simultaneously done polysomnography (n=53); Spearman's rank correlation coefficient=0.316 for RDIH ($p<0.05$) and 0.329 for RDIS ($p<0.05$).

To elucidate clinical usefulness of the RDI's from the two screening systems, we classified our patients in two groups according to the difference between the computer calculated RDI and the AHI from polysomnography: group I, if the RDI differed less than 30% from the AHI, and group II, if the RDI differed more than 30 % from the AHI. Obviously, this 30% limit was entirely arbitrary, but was assumed to represent the level of inaccuracy above which the analysis of this patient would have to be classified as wrong.

As shown in figure 3, the RDIR classified 77% of the patients within this plus/minus 30% difference from the true AHI. The corresponding numbers for the other RDI's were: 62% for the RDID, 32% for the RDIS and 23% for the RDIH.

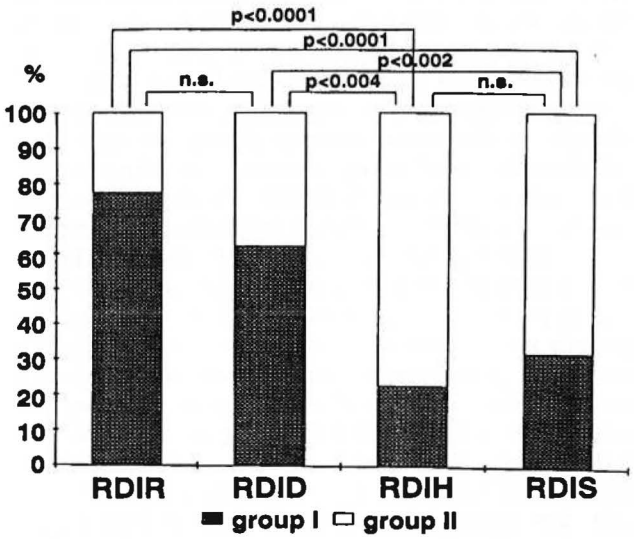


Fig. 3. – Distribution of patients (n=53) in groups according to the difference between the computer calculated respiratory disturbance index (RDI) and the polysomnographical apnoea plus hypopnoea index (AHI). Group I: error<±30%, group II: error>±30%.

## Discussion

This study shows that computerized quantification of sleep disordered breathing from screening studies for OSAS correlates more closely with polysomnography when done from overnight $Sao_2$ recordings than when done from analysis of heart rate and snoring sounds.

Although cyclic variation of heart rate is a characteristic feature of OSAS [13], quantification of nocturnal respiratory disturbances by the intervals of constant heart rate, as done by the MESAM software, gives rather poor results. A change in instantaneous heart rate has to exceed 10% compared with the mean value of the last 5 min to be included in the calculation of the RDIH by MESAM. From this, one would expect that the MESAM software rather underestimates the AHI, especially if baseline heart rate is high. In fact, this was true in some patients, but in the majority of patients the RDIH rather overestimated the AHI. Possible explanations for this could be changes in instantaneous heart rate due to premature beats not associated with sleep apnoea, as well as artifacts.

Since absence of breathing sounds is a sign directly related to apnoea, it is surprising that the RDIS calculated from the time intervals between snoring sounds correlated rather weakly with the AHI. Although all night snoring was observed in all of the patients in the sleep lab, we found some outprints of MESAM showing only short periods of snoring. Thus, technical problems like dislocation of the microphone dependent on body position appear to be the major cause for underestimation of the AHI by the RDIS. Furthermore, some OSAS patients disturb the analysis of intervals between snoring sounds by creating noise during apnoeic events. Dependent on the frequency spectrum and timing of these noises, this might result in over- as well as underestimation of the AHI by the RDIS. Since persisting breathing sounds during hypopnoeas preclude recognition of these events from intervals between snoring sounds, we calculated also the correlation of the RDIS with the pure apnoea index, but the result ($r = 0.472$, $p<0.001$) was not much better than for the AHI.

Since changes in $Sao_2$ are almost invariably due to changes in respiration whereas changes in heart rate and the creation of laryngeal sounds are influenced by numerous other factors, both RDI's from computerized analysis of oximetry quantified respiratory disturbances during sleep more accurately than MESAM. We found RES to be more sensitive than DESAT to detect apnoeas and hypopnoeas in patients with low AHI [20]. In patients with numerous events per hour, the RDIR and the RDID were nearly equal. Lower sensitivity of DESAT might be attributed to the limit for a desaturation to be detected by the computer being set to a 4 percent fall in $Sao_2$. This limit was not included in our definition of hypopnoea from polysomnography because only few hypopnoeic events do cause a desaturation exceeding 4%. Since even apnoeas do not invariably cause significant desaturations, both factors make the RDID rather underestimate the AHI.

The abrupt resumption of ventilation during the arousal following apnoea or relevant hypopnoea is associated with loud snoring and a rapid increase in $Sao_2$. Therefore, the RDIR and the RDIS should theoretically be equal, but we did not find this. However, there was a weak but significant correlation between the RDIS and polysomnography, which is in contrast to a recent study [22] showing no significant correlation even when looking only at patients with an apnoea index above 10.

Although the automatically calculated RDI's from oximetry correlated very closely with polysomnography, a considerable over- or underestimation of the true number of apnoeas and hypopnoeas was found in some individual patients. It should be emphasized that even the RDIR - which classified more patients within plus/minus 30% of the true AHI than all the other RDI's - gives only a rough estimation of the amount of respiratory events in more than 20% of the patients. However, neither oximetry nor MESAM are thought as a replacement for polysomnography. The value of both methods lies in the feasibility to obtain a yes or no decision about the presence of relevant sleep apnoea by a simple, cheap method. In fact, looking at the outprints, a prompt decision about the patient's recording being normal or abnormal was possible with both screening methods.

In conclusion, we found that computerized quantification of sleep disordered breathing correlates more closely with polysomnography when done from oximetry than from MESAM. Computerized search for desaturations and rapid resaturations classified more patients within plus/minus 30% from the polysomnographical AHI than automatic analysis of heart rate and snoring intervals.

## References

1. Fletcher EC, DeBehnke RD, Lovoi MS, Gorin AG. – Undiagnosed sleep apnea in patients with essential hypertension. *Ann Intern Med*, 1985, 103, 190–195.
2. Williams AJ, Houston D, Finberg S, Lam C, Kinney JL, Santiago S. – Sleep apnea syndrome and essential hypertension. *Am J Cardiol*, 1985, 55, 1019–1022.
3. Gonzalez-Rothi RJ, Foresman GE, Block AJ. – Do patients with sleep apnea die in their sleep? *Chest*, 1988, 94, 531–538.
4. Partinen M, Jamieson A, Guilleminault C. – Long-term outcome for obstructive sleep apnoea syndrome patients. *Chest*, 1988, 94, 1200–1204.
5. He J, Kryger MH, Zorick FJ, Conway W, Roth T. – Mortality and apnea index in obstructive sleep apnea. Experience in 385 male patients. *Chest*, 1988, 94, 9–14.
6. Partinen M, Guilleminault C. – Daytime sleepiness and vascular morbidity at seven-year follow-up in obstructive sleep apnea patients. *Chest*, 1990, 97, 27–32.
7. Findley LJ, Unverzagt ME, Suratt PM. – Automobile accidents involving patients with obstructive sleep apnea. *Am Rev Respir Dis*, 1988, 138, 337–340.
8. George C, Nickerson P, Hanly P, Millar T, Kryger M. – Sleep apnea patients have more automobile accidents (letter). *Lancet*, 1987, 1 (8556), 447.

9. Guilleminault C. – Clinical features and evaluation of obstructive sleep apnea. *In:* Principles and practice of sleep medicine. M.H. Kryger , T. Roth, W.C Dement eds. W.B.Saunders, New York, 1989, pp 552–558.
10. Cummiskey JM, Williams TC, Krumpe PE, Guilleminault C. – The detection and quantification of sleep apnea by laryngeal sound recordings. *Am Rev Respir Dis*, 1982, 126, 221–224.
11. Penzel T, Amend G, Meinzer K, Peter JH, von Wichert P. – MESAM: A heart rate and snoring recorder for detection of obstructive sleep apnea. *Sleep*, 1990, 13, 175–182.
12. Farney RF, Walker LE, Jensen RL, Walker JM. – Ear oximetry to detect apnea and differentiate rapid eye movement (REM) and non-REM (NREM) sleep. *Chest*, 1986, 89, 533–539.
13. Guilleminault C, Connoly S, Winkle R, Melvin R. – Cyclical variation of the heart rate in sleep apnea syndrome: mechanisms and usefulness of 24 h electrocardiography as a screening technique. *Lancet*, 1984, 1, 126–131.
14. Steyer BJ, Quan SF, Morgan WJ. – Polysomnography scoring for sleep apnea. Use of a sampling method. *Am Rev Respir Dis*, 1985, 131, 592–595.
15. Guilleminault C, Cumminsky J, Dement WC. – Sleep apnea syndrome: recent advances. *Adv Intern Med*, 1980, 26, 347–372.
16. George CF, Millar TW, Kryger MH. – Identification and quantification of apneas by computer-based analysis of oxygen saturation. *Am Rev Respir Dis*, 1988, 137, 1238–1240.
17. Gould GA, Whyte KF, Rhind GB, Airlie MA, Caterall JR, Shapiro CM, Douglas NJ. – The sleep hypopnea syndrome. *Am Rev Respir Dis*, 1988, 137, 895–898.
18. Wilhoit SC, Suratt PM, Evans RJ, Brown ED, Kaiser DL. – Comparison of indices used to detect hypoventilation during sleep. *Respiration*, 1985, 47, 237–242.
19. Guilleminault C, van den Hoed J, Mitler M. – Clinical overview of the sleep apnea syndromes. *In:* Sleep apnea syndromes. C. Guilleminault, W. Dement eds. Alan R. Liss,New York, 1978, pp 1–12.
20. Rauscher H, Popp W, Zwick H. – Screening for sleep apnea by oxymetry. *Am Rev Respir Dis*, 1990, 141, A859.
21. Rechtschaffen A, Kales A. – A manual of standardized terminology techniques and scoring systems for sleep stages of human subjects. National Institute of Health eds. Washington DC, 1968, Publ. No. 204.
22. Stoohs R, Guilleminault C. – Investigations of an automatic screening device (MESAM) for obstructive sleep apnea. *Eur Respir J*, 1990, 3, 823–829.

*Quantification des troubles respiratoires pendant le sommeil au moyen d'une analyse computérisée de l'oxymétrie, du rythme cardiaque et du ronflement. H. Rauscher, W. Popp, H. Zwick.*

RÉSUMÉ: Le ronflement intermittent et les oscillations cycliques du rythme cardiaque et de la saturation de l'oxyhémoglobine ($Sao_2$) sont des traits caractéristiques du syndrome d'apnée obstructive du sommeil. Dans ces conditions, l'enregistrement nocturne des sons laryngés et du rythme cardiaque au moyen d'une instrumentation portable (MESAM) et de celui de la $Sao_2$ par oxymétrie, peuvent être utilisés pour dépister le syndrome d'apnée obstructive du sommeil chez les patients. L'analyse computérisée des intervalles de temps de rythme cardiaque constant et des intervalle entre les sons de ronflement, est utilisée par le MESAM pour quantifier les troubles respiratoires pendant le sommeil. Les augmentations rapides de la $Sao_2$ au cours de l'hyperventilation post-apnéique, ainsi que le nombre de désaturations, sont employés dans un nouveau logiciel pour l'analyse quantitative de l'oxymétrie. Pour apprécier la fiabilité des résultats obtenus par les scores MESAM automatiques et les enregistrements oxymétriques, nous avons comparé les quatre indices de troubles respiratoires calculés par ordinateur à partir du rythme cardiaque (RDIH), du ronflement (RDIS), des resaturations (RDIR) et des désaturations (RDID), avec l'index d'apnée plus hypopnée (AHI) obtenus à partir d'une polysomnographie simultanée. La population étudée comportait 53 ronfleurs dont l'AHI était de 19.0±2.6 (médiane±SEM; extrêmes 0.7–87.8) Alors que les deux RDI obtenus par le MESAM avaient une corrélation plutôt faible avec l'AHI polysomnographique (RDIH: $r = 0.32$, $p<0.05$; RDIS: $r=0.33$, $p<0.05$), cette corrélation était beaucoup meilleure pour les RDI obtenus par oxymétrie (RDIR: $r = 0.951$, RDID: $r = 0.93$, $p<0.0001$). En acceptant une différence de plus ou moins 30% autour de l'AHI, le RDIR a classifié correctement 77% des patients, le RDID 62%, le RDIS 32%, et le RDIH 23%. En conclusion, les résultats de l'analyse computérisée de l'oxymétrie pour les désaturations et les resaturations rapides, sont en corrélation plus étroite avec la polysomnographie que ceux provenant d'enregistrements automatiques à partir de scores MESAM. *Eur Respir J., 1991, 4, 655–659.*