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Suitability of New Methods for Pulseoximetric Data Analysis in Screening Diagnostics of Respiratory Disorders During Sleep (RDDS)

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Pulseoximetry is the simplest and the most reliable screening test for diagnosing of Respiratory Disorders During Sleep. Assessment of blood saturation with oxygen is a basic parameter to determine the degree of SAS (Sleep Apnea Syndrome) progression. The authors describe the conventional, but also their own newly developed methods for pulseoximetric data analysis, tested for over 4500 patients. The purpose of these new methods is to give physicians easier and more simple means for evaluating patients after all-night blood oxygen saturation monitoring. Inventiveness of this method lies in the possibility of examining of dynamics of blood oxygen saturation during patient's sleep. All received data are stored and can be reported in special 1-hour step intervals to facilitate comparative analysis of subsequent examinations and assess effectiveness of the treatment.

K e y w o r d s: biomeasurement, pulseoximetry, Respiratory Disorders During Sleep, Sleep Apnea Syndrome

1. Introduction

Diagnostics of Respiratory Disorders During Sleep (RDDS) is a relatively new and dynamically developing area of medical science. A characteristic feature of these disorders that are also referred to as unrecognized dyspnea is a significant impediment or even lack of air flow through the upper respiratory tract during patient's sleep due to obturation of the upper respiratory tract or disturbances of the central stimulation of the respiratory drive. The extreme and most severe form of the RDDR is the Sleep Apnea Syndrome (SAS) [1, 2]. A direct consequence of these abnormalities result is hypoxia of the organism, which is the most evident in results of blood saturation measurements. The Respiratory Disorders During Sleep are a common phenomenon that affects over 5% of

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total population. Due to high requirements with respect to medical personnel and a high cost of a polysomnographic (PSG) examination that involves an all-night recording of physiological signals in order to assess the sleep and breathing parameters, saturation of the blood with oxygen and the heart functions, it is not possible to apply the PSG for the RDDS diagnostics in large-scale screening tests [3, 4, 5]. At present, the most urgent issue is to initiate the RDDS screening examinations that would be characterized in general availability and simple equipment and that would allow for a reliable interpretation correlated with the RDDS. It seems that the nocturnal pulseoximetry fulfils all these requirements. Our experience shows that the pulseoximetry is the most simple and reliable screening test in the RDDS diagnostics. Blood saturation measurement is one of the basic tools to be used in assessing progression of the RDDS.

2. Purpose

The purpose of this work was to assess suitability of our original methods of pulseoximetric data analysis in the screening diagnostics of RDDS. This paper presents conventional and novel methods for analyzing pulseoximetric data, based upon our own experiments as well as on over 4,500 clinical examinations. A reliable assessment of dynamics of blood saturation changes that are reflecting the progression of RDDS, is the key advantage of the novel methods. The conventional method of analyzing pulseoximetric data (Fig. 1) is based mainly upon statistical assessment of the fraction of the particular pulse and saturation values with respect to the entire examination. The method provides information about mean, maximum and minimum values and graphical representation of distribution of all the pulse and saturation parameters. However, the analysis does not allow for assessing of the dynamics of saturation changes or its morphology. It is not possible to determine whether abnormal test results are the RDDS – related or rather a result of a pulmonary or bronchial disease.

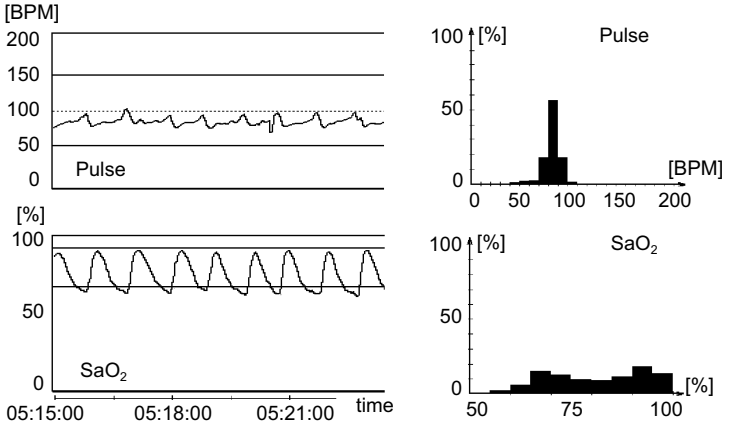

Fig. 1. Conventional analysis – time fluctuations and percentage distribution of pulse and saturation (SaO_2)

Another conventional parameter is the oxygen desaturation index (ODI) that provides the number of episodes when the level of oxygen in blood drops down by ≥4% within 1 hour of sleep. Anyway, ODI does not account for entire dynamics and morphology of the saturation changes. The most important novel methods include measurement of distribution of saturation drops, the saturation change coefficient (SCC), a graphical presentation of the function F(SaO_2, Pulse), the desaturation coefficient (DC), and the desaturation vector (DV).

3. Methods and Comparative Analysis

The RDDS is recognized if shallow breath or lack of airflow through the upper respiratory tract appear at least ten times (some authors recommend – five times) per one hour of sleep with accompanying saturation drops by at least 4%. The novel methods are based upon assessment of the magnitude and frequency of blood saturation changes (Fig. 2). Results are presented for the entire examination and in the form of 1-hour intervals.

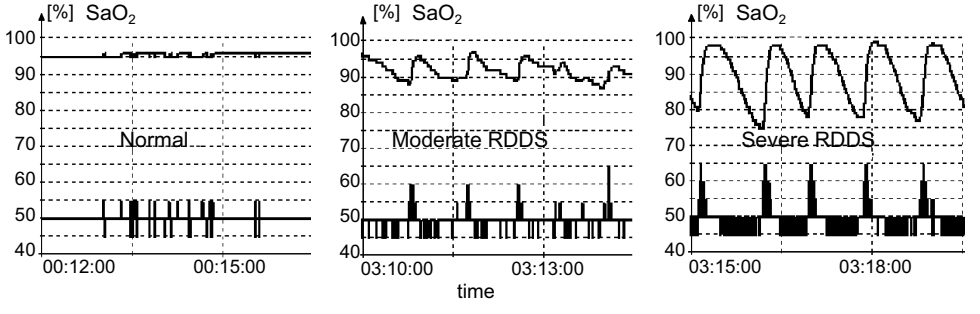

Fig. 2. Characteristic 4.5-minute records of blood saturation changes in subjects with normal saturation and with various degrees of RDDS

3.1. Distribution of Saturation Changes Magnitude

Disregarding the value of the desaturation index (ODI), magnitude of the saturation drops is the best measure of the RDDS severity (Fig. 2). Changes of this parameter are presented as distribution of the number of episodes when the saturation decreases by a given factor (≥4%) during the entire examination and as the average saturation decrease in 1-hour intervals (Fig. 3).

In the case when different patients have the same or similar average drop of all-night saturation, the distribution graphs allow for, e.g., differentiating between the RDDS and restrictive respiratory disorders.

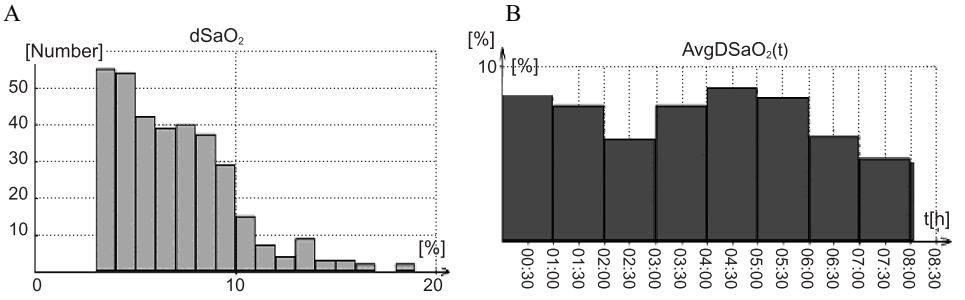

Fig. 3. Distribution of the number of episodes when saturation ($dSaO_2$) drops down by a given factor (A) and average saturation drops ($AvgDSaO_2$) in 1-hour time intervals (B) in a RDDS patient

3.2. Saturation Change Coefficient (SCC)

The SCC is the most sensitive parameters for assessing the dynamics of blood saturation changes and, unlike any other methods discussed in this paper, accounts for one-percent variations. In brief, the SCC is a modified derivative of the blood saturation changes (1), and its magnitude is proportional to the magnitude and frequency of the saturation drops.

$$SCC = \sqrt{\frac{\left(\sum_{i=1}^{T}\left(t_i - t_{i-1}\right)\Big|_{\left(S_i(t_i)-S_{i-1}(t_{i-1})\right)\neq 0}\right)\cdot\left(\sum_{i=1}^{T}\left|S_i\left(t_i\right) - S_{i-1}\left(t_{i-1}\right)\right|\right)}{T^2}}\cdot 100 \qquad (1)$$

where: T – duration of the examination, t_i – i-th time point of the examination, $S_i(t_i)$ – saturation at the time point t_i.

The SCC is calculated as a single value for the entire examination and as a distribution for 1-hour intervals (Fig. 4). The SCC values that are determined experimentally and correlated with the health condition of the examined individual are as follows: normal – from 0 to 2, RDDS – from 6 to 100, for the values from 3 to 5, a decision should be based upon a visual examination or upon the value of the desaturation index ODI.

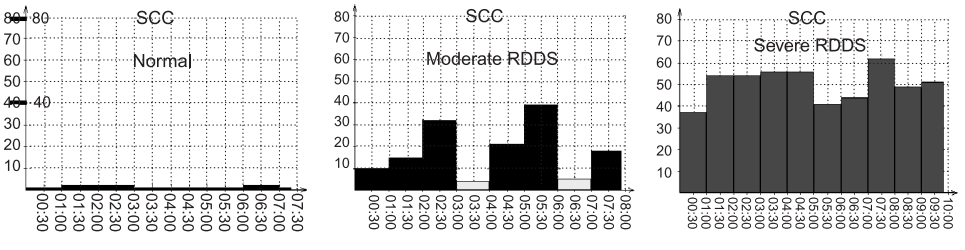

Fig. 4. SCC distribution in 1-hour time intervals in normal individuals and in various degrees of RDDS

3.3. Graphical Representation of the Function F(SaO_2, Pulse)

Graphical representation of the function F(SaO_2, Pulse) presents all interrelations between the pulse and saturation values that are possible in time and space (2). The matrix is a convenient means for visual assessment of a pulseoximetric examination (Fig. 5); it allows for a general assessment of dispersion and, by manipulating a time lag slide, internal correlation between SaO_2 and the pulse.

$$F(S,P)=\sum_{i=0}^{T}\begin{bmatrix} \begin{cases}1{:}S_i(t_i)=0,P_i(t_i)=0\\ 0{:}S_i(t_i)\neq 0,P_i(t_i)\neq 0\end{cases} & \begin{cases}1{:}S_i(t_i)=0,P_i(t_i)=1\\ 0{:}S_i(t_i)\neq 0,P_i(t_i)\neq 1\end{cases} & \cdots & \begin{cases}1{:}S_i(t_i)=0,P_i(t_i)=200\\ 0{:}S_i(t_i)\neq 0,P_i(t_i)\neq 200\end{cases} \\ \begin{cases}1{:}S_i(t_i)=1,P_i(t_i)=0\\ 0:S_i(t_i)\neq 1,P_i(t_i)\neq 0\end{cases} & \begin{cases}1{:}S_i(t_i)=1,P_i(t_i)=1\\ 0{:}S_i(t_i)\neq 1,P_i(t_i)\neq 1\end{cases} & \cdots & \begin{cases}1{:}S_i(t_i)=1,P_i(t_i)=200\\ 0{:}S_i(t_i)\neq 1,P_i(t_i)\neq 200\end{cases} \\ \cdots & \cdots & \cdots & \cdots \\ \begin{cases}1{:}S_i(t_i)=100,P_i(t_i)=0\\ 0{:}S_i(t_i)\neq 100,P_i(t_i)\neq 0\end{cases} & \begin{cases}1{:}S_i(t_i)=100,P_i(t_i)=1\\ 0{:}S_i(t_i)\neq 100,P_i(t_i)\neq 1\end{cases} & \cdots & \begin{cases}1{:}S_i(t_i)=100,P_i(t_i)=200\\ 0{:}S_i(t_i)\neq 100,P_i(t_i)\neq 200\end{cases} \end{bmatrix} \quad (2)$$

where: S – SaO_2, P – pulse, T – examination time, t_i – i-th time point of the examination, $S_i(t_i)$ – SaO_2 at the time point t_i, $P_i(t_i)$ – pulse at the time point t_i.

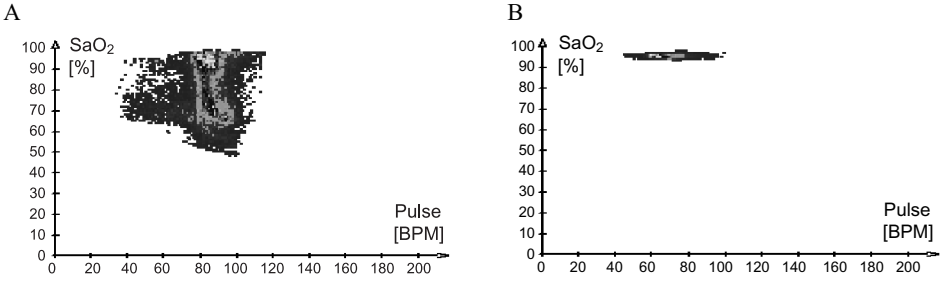

Fig. 5. Matrix F(SaO_2, Pulse) for individuals with severe RDDS (A) and normal (B)

3.4. Desaturation Coefficient (DC) and Desaturation Vector (DV)

The desaturation coefficient (DC) is a bi-parametric quantity that is proportional both to square root of the product of the desaturation index (ODI) and the magnitude of saturation drops ($AvgDSaO_2$) (3). It is calculated as a single value for the entire examination and as a distribution for 1-hour intervals (Fig. 6). The DC values that are determined experimentally and correlated with the health condition of the examined individual are as follows: normal – from 0.00 to 5.49, RDDS – from 5.50 to 40.00. The desaturation vector (DV) is a two-dimensional vector, components of which are the desaturation index and the magnitude of saturation drops (4). The diagnostic decision area is marked within this space (Fig. 6). Aside from diagnostic assessment, DC and DV ensure substantial objectivity of the RDDS treatment results.

$$DC = \sqrt{ODI * AvgDSaO_2} \tag{3}$$

$$DV = \sqrt{(ODI)^2 + (AvgDSaO_2)^2} \tag{4}$$

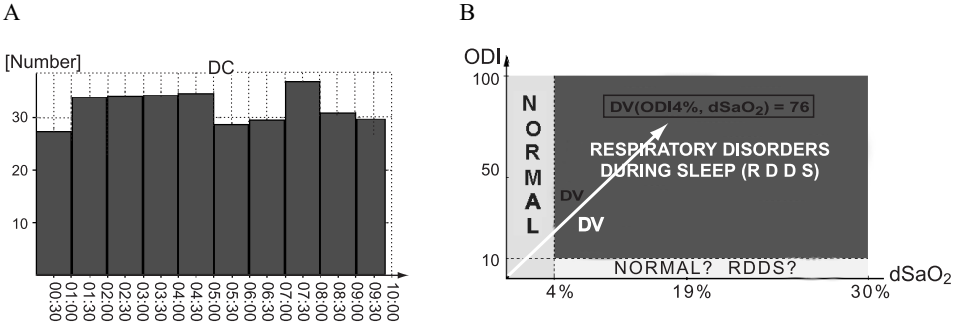

Fig. 6. Desaturation coefficient DC (A) and desaturation vector DV (B) with a decision area for an individual with severe RDDS

4. Conclusion

The novel data analysis methods, implemented in our pulseoximetric systems ensure quick detection of the RDDS and good assessment of the RDDS progression. The methods facilitate intra- and interpersonal comparative analysis, unlike the statistic method they account for morphologic assessment of changes in saturation (dynamics) and allow for more reliable assessment of casual treatment results. Presentation of data in the form of 1-hour intervals ensures substantial objectivity of comparative analysis of subsequent examinations and assesment of the RDDS treatment results. On grounds of the pulseoximetric examinations, performed so far in over 4,500 individuals who have been also subject to other examinations with respect to the RDDS diagnostics, we conclude that pulseoximetry is sufficiently effective and the most reliable method for screening tests in the Respiratory Disorders During Sleep (RDDS) diagnostics.

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