

# Signal Processing Procedures for the Evaluation of the Cardiovascular Effects in the Obstructive Sleep Apnea Syndrome

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## Abstract

A new index, the Cross-Power Index (CPI), is proposed to quantify the severity of obstructive sleep apnea syndrome (OSAS) in terms of its cardiovascular effects. On the basis of the influences that recurring drops in oxygen saturation have on systolic blood pressure variability of OSAS patients, CPI is defined as the integral of the cross-spectrum modulus between systolic blood pressure and oxygen saturation.

In a test group of 22 subjects CPI correctly identified all the 15 OSAS patients included in the pool. Moreover, evaluation of CPI in 6 OSAS patients sleeping without and with a CPAP device demonstrated that CPAP treatment substantially reduced the components of blood pressure variability correlated to oxygen saturation. These first applications of CPI support the use of this index to identify OSAS patients, to evaluate the efficacy of CPAP in their treatment, and to quantify the cardiovascular effect of OSAS.

## 1. Introduction

Obstructive sleep apnea syndrome (OSAS) is a sleep disorder occurring in 2-4% of the middle aged population [1]. It is characterized by recurring cessations of breathing, due to a collapse of the upper airways, which produces a drop in oxygen saturation and an increase of CO<sub>2</sub>, in turn triggering a central nervous activation, called arousal. Arousals terminate the apnea by restoring respiration for a few breaths and are associated with sympathetic activations and abrupt temporary elevations of blood pressure.

In the most severe cases, the apnea-arousal cycle may occur hundreds of times per night (see an example in fig.1). This means an important sleep fragmentation and a consequent daytime drowsiness. Moreover, the frequent occurrence of apnea-arousal episodes also implies a repeated occurrence of the hypertensive peaks characterizing the onset of each arousal and this may represent an important and dangerous stress for the cardiovascular system. Actually, OSAS patients display an elevated cardiovascular morbidity and mortality and the hypertensive peaks induced by the apnea-arousal

cycle may be among the factors responsible for this increased risk [2,3].

The assessment of OSAS is based on the overnight multichannel polysomnography of the subject performed in a specialized laboratory. This procedure usually includes continuous recordings of EEG, EMG, ECG, electro-oculography, nasal airflow, rib-cage and abdominal motions, blood pressure and oxygen saturation, SaO<sub>2</sub>. The diagnosis is based on the frequency and duration of apneic episodes and arousals, and on the alterations of the sleep cycle.

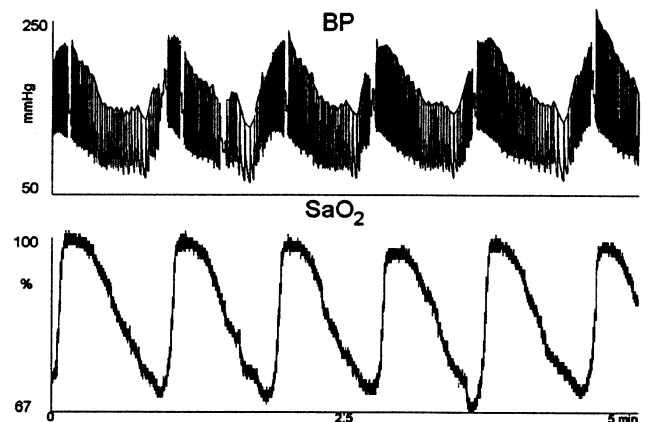


Figure 1. Five min. recording of blood pressure, BP, and oxygen saturation SaO<sub>2</sub> during sleep in a severe OSAS patient.

The severity of OSAS is quantified by indexes derived from polysomnographies like the apnea-hypopnea index, AHI (defined as the hourly rate of apnea and hypopnea episodes) and the relative duration of each sleep stage. These indexes quantify the degree of impairment of the respiratory function, or the level of sleep fragmentation due to OSAS but leaves virtually unexplored the effects of OSAS on blood pressure variability and, more specifically, on the post-apneic hypertensive peaks.

Aim of this work is to propose a new index to quantify the severity of OSAS from the perspective of blood pressure variability. In the first part of this work, the index is defined on the basis of the effects that recurring

drops on oxygen saturation have on systolic blood pressure (SBP) variability of OSAS patients. In the second part, the capability of this index to discriminate between OSAS patients and healthy volunteers by quantifying the fraction of blood pressure variability induced by changes in oxygen saturation is tested. Then, the index is also applied to evaluate the cardiovascular effects of the acute treatment by nasal continuous positive airway pressure (CPAP) device in a group of severe OSAS patients.

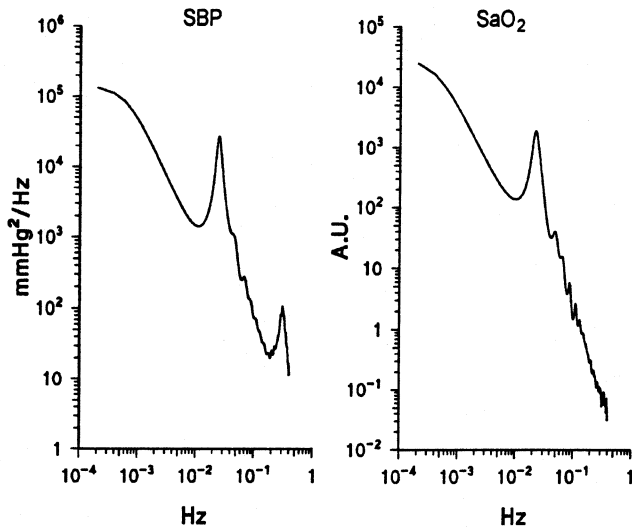


Figure 2. SBP (left) and SaO<sub>2</sub> (right) power spectra in a OSAS patient during sleep.

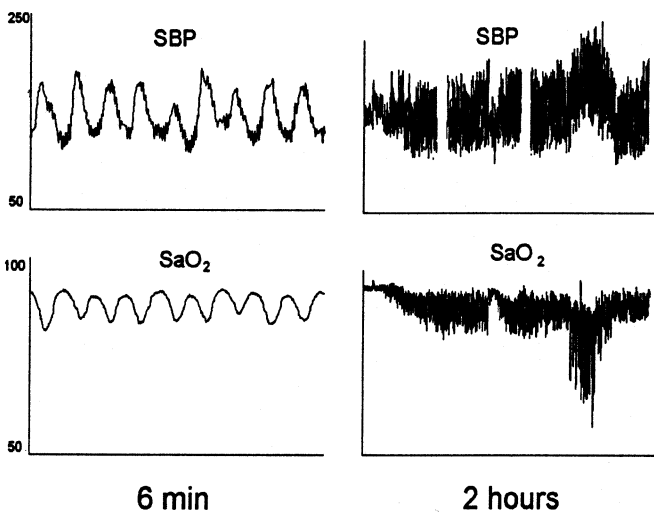


Figure 3. Short- and long-term modulations of systolic blood pressure, SBP, and oxygen saturation, SaO<sub>2</sub>, in a OSAS patient. Influences of SaO<sub>2</sub> dynamics on SBP variability may extend to broadband components of variability.

## 2. The Cross-Power Index CPI

When a sequence of arousals is plotted on a relatively short time scale (see fig.1), the SaO<sub>2</sub> dynamics appears like a regular oscillation which produces a similar fluctuation in blood pressure. The effects of the SaO<sub>2</sub> oscillation on blood pressure could be quantified by the power of the spectral peak which appears clearly in the SBP spectrum at the same frequency of the SaO<sub>2</sub> oscillation (fig.2 left). However, the SaO<sub>2</sub> spectrum (fig.2, right) shows not only this peak, but also a "1/f" trend [5]. Thus it is possible that the influences of SaO<sub>2</sub> changes on blood pressure variability may also extend over a broad range of lower frequencies. This is strongly suggested by fig.3, in which SaO<sub>2</sub> shows a more complex dynamics when time-scales longer than few minutes are considered. During sleep, the SaO<sub>2</sub> variability also shows long-term modulations of the baseline and of the amplitude of the SaO<sub>2</sub> drops which are clearly correlated to similar long-term modulations of blood pressure. Thus, also broadband components of SBP variability should be taken into account to more completely quantify the effects of OSAS on blood pressure changes.

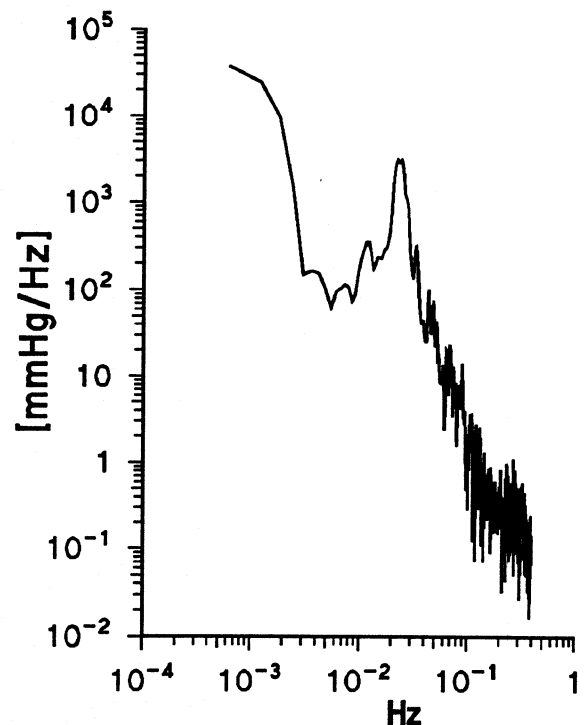


Figure 4. Modulus of the cross-spectrum between SBP and SaO<sub>2</sub> in the same patient of fig.2.

A way to quantify the components of SBP variability modulated by broadband changes of SaO<sub>2</sub> is to compute the cross-spectrum  $G_{XY}(f)$  between SBP and SaO<sub>2</sub>. The modulus of the cross-spectrum gives a measure at each frequency  $f$  of the SaO<sub>2</sub> and SBP powers which are

linearly correlated. Figure 4 shows an example of the cross-spectrum modulus during sleep in a OSAS patient. As the example shows, the main contributions come from the very-low frequency peak and from the lower frequencies of the "1/f" trend.

In order to quantify the overall influences of SaO<sub>2</sub> changes on SBP variability by means of a single index, we propose to compute a new index, called the Cross-Power Index CPI, defined as the integral of the modulus of the cross-spectrum between SBP and SaO<sub>2</sub>:

$$CPI = \int |G_{XY}(f)| df$$

By integrating  $|G_{XY}(f)|$  over the whole frequency axis, we get a global measure of SBP and SaO<sub>2</sub> correlated changes.

### 3. Applications of the Cross-Power Index CPI

In order to evaluate the capability of the new index to identify OSAS, CPI was firstly assessed in 15 severe OSAS patients (AHI > 50 n/h) and in 7 normal volunteers. Then, to evaluate how CPAP treatment may reduce the cardiovascular effects of OSAS, CPI was calculated again in 6 patients of the severe OSAS group who underwent a second polysomnography session sleeping with a CPAP device.

In each subject, a complete multichannel polysomnography was performed overnight. Each polysomnography had at least 5 hours of continuous recording during sleep. To compute CPI, only blood pressure and SaO<sub>2</sub> signals were considered. Signals were sampled at 100 Hz and SBP was estimated on a beat-by-beat basis from the continuous blood pressure waveform. Then the SBP series and the SaO<sub>2</sub> signal were interpolated and resampled evenly at 2.5 Hz. The cross-spectrum between SBP and SaO<sub>2</sub> was computed by the Welch method [4], i.e. by splitting SBP and SaO<sub>2</sub> signals into 50% overlapped Hann windows, each of length 1200 s; by computing the FFT cross-spectrum in each window; and by averaging all the FFT cross-spectra. Finally, CPI was calculated by integrating the averaged cross-spectrum modulus.

#### 3.1. Results

Individual values of CPI in the whole group of subjects are shown in figure 5. Distributions of CPI values are markedly different in the OSAS patients and healthy subjects. Indeed, CPI is invariably lower than 5 mmHg in the control group – with 90% tolerance limits ranging from 2.6 to 4.8 mmHg – and significantly higher for OSAS subjects – the tolerance limits of this group ranging from 32 to 97 mmHg. Such a marked separation

of CPI values between normal and OSAS subjects suggests the use of this index as a prospective diagnostic tool for the classification of the OSAS subjects.

CPI values of 6 OSAS patients who also underwent a second polysomnography during a CPAP treatment are shown in figure 6. CPI dramatically decreased in all patients when the CPAP device was used, and reached the normal levels in 4 of 6 cases.

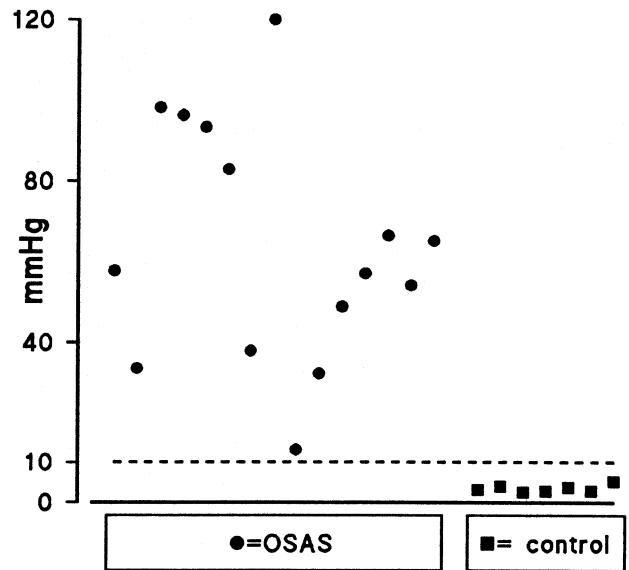


Figure 5. CPI in 15 OSAS patients and in 7 healthy controls; a threshold at 10 mmHg (dashed line) can discriminate patients from healthy subjects.

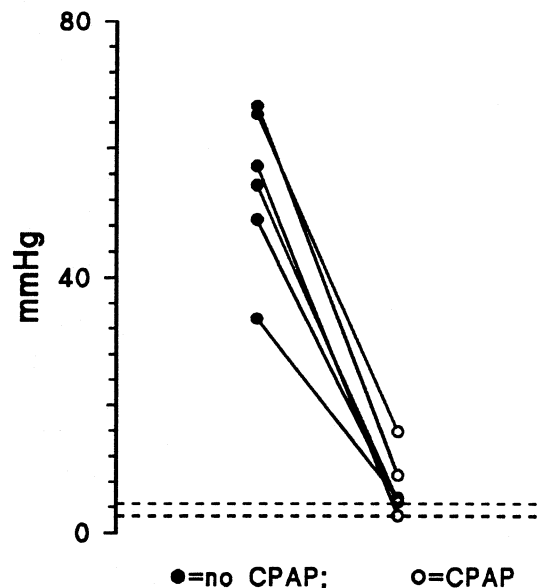


Figure 6. CPI in 6 severe OSAS patients sleeping without (open circle) and with (solid circle) CPAP device; dashed lines show the 90% tolerance limits for the healthy population.

It is worth noting that information given by CPI can not be predicted by using other indexes of OSAS severity like AHI. This is illustrated in figure 7, which shows two short segments of SBP and SaO<sub>2</sub> data recorded in a patient before and after a 6-month treatment with CPAP. Treatment had no effects on the respiratory function of this patient, and the apnea-hypopnea index measured from the whole 6-h recording during sleep increased slightly, from 93 to 99 events/hour, suggesting a worsening of OSAS. However, CPI measured from the whole night recordings in the same patient decreased considerably, dropping from 82 to 47 mmHg, indicating a significant improvement of the patient conditions from the cardiovascular point of view.

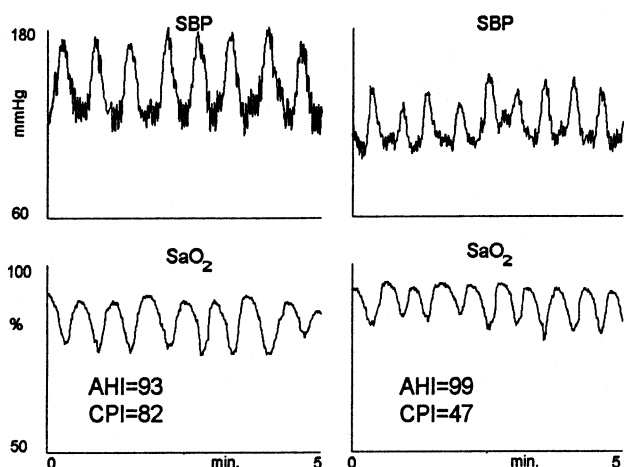


Figure 7. Five minutes of SBP and SaO<sub>2</sub> in a OSAS patient before (left) and 6 months after (right) CPAP treatment (treatment discontinued during the recording); apnea-hypopnea index (AHI) and cross-power index (CPI) from the whole sleeping periods are shown.

#### 4. Conclusions

In this work we proposed a new index, the cross power index CPI, for the quantification of the severity of OSAS. The index has been defined on the basis of the characteristics of blood pressure variability and SaO<sub>2</sub> dynamics observed in a group of OSAS patients. Information provided by this index appears to be independent from traditional indexes derived from polysomnographies, like AHI. An important advantage of the proposed cross-power index is that it does not require

full polysomnography to be measured. In fact, it could be assessed just from an overnight monitoring of continuous blood pressure (now routinely performed in hypertensive subjects by means of portable devices) and oxygen saturation. Since also oxygen saturation may be measured by means of portable devices, CPI could be assessed with the subject sleeping at his/her own home and not in the polysomnography laboratory.

Our preliminary results suggest the prospective use of CPI as a tool to discriminate OSAS patients from healthy subjects. For this reason, assessment of CPI might allow a first screening of the population of hypertensive subjects in search for OSAS patients, being the hypertensive patients a group in which OSAS has a high incidence and may represent an additional risk factor. Moreover, CPI may usefully complement other indexes for the diagnosis of OSAS by quantifying OSAS severity also in terms of its cardiovascular effects, and may be used to evaluate the efficacy of treatments.

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