Cardiac Risk Index – A New Severity Indicator for Sleep-disordered Breathing and Cardiovascular Disease

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Abstract

Cardiovascular disease (CVD) is among the world’s leading causes of morbidity and mortality. Statistics show 30% of deaths worldwide can be attributed to CVD, with nearly 40% in high-income countries and about 28% in low- and middle-income countries. Behavioural factors such as physical inactivity, smoking and diet, and metabolic factors, e.g., dyslipidaemia, diabetes and hypertension, are risk factors for CVD. Studies have shown that patients suffering from obstructive sleep apnoea (OSA) face an increased risk of CVD. Given the high prevalence of non-fatal and fatal cardiovascular events, an early cardiovascular risk assessment is an important tool in clinical practice. Current research shows that analysis of the pulse wave, which is recorded by pulse oximetry over the course of a night, presents new diagnostic and prognostic possibilities. Known as autonomic state indicator concept (ASIC), this method enables the physician to assess the risk and severity of sleep-disordered breathing and the cardiovascular risk to the patient. It is expected that this method will significantly change the work done by somnologists, pneumologists, cardiologists, general practitioners and doctors specialised in preventive care.

Keywords

Cardiovascular risk, sleep-disordered breathing, obstructive sleep apnoea (OSA), autonomic state indicator (ASIC), pulse wave, photoplethysmography, oxygen desaturation, pulse oximetry

Disclosure: Martina Bögel is an employee of Weinmann GmbH & Co KG.
Received: 31 January 2012 Accepted: Day Month Year Citation: European Respiratory Disease, 2012;8(1):xx –x
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Support: The publication of this article was funded by Weinmann GmbH & Co KG.

Cardiovascular disease (CVD) is among the world’s leading causes of morbidity and mortality. Statistics show 30% of deaths worldwide can be attributed to CVD, with nearly 40% in high-income countries and about 28% in low- and middle-income countries. Behavioural factors such as physical inactivity, smoking and diet, and metabolic factors, e.g., dyslipidaemia, diabetes and hypertension, are risk factors for CVD. Longitudinal studies have repeatedly proven increased cardiovascular morbidity and mortality in obstructive sleep apnoea (OSA) patients. An elevated risk has also been observed in mild untreated cases of OSA. The negative effect of OSA on the cardiovascular system appears to be particularly potent in young patients. Evidence of this effect was provided by a long-term follow-up study involving a large population of 15,000 patients. Effective continuous positive airway pressure (CPAP) therapy, however, has been found to have a positive effect on the cardiovascular system.

The cardiovascular risk measured in the studies with OSA patients is a statistical value. It is still unknown which patients are at risk and how great the risk is. The risk does not necessarily correlate with the severity of the nocturnal respiratory disorder. How can patients with an increased cardiovascular risk be quickly and reliably identified? A new non-invasive method that uses the indices of the autonomic system during sleep provides more information about this group.

Figure 1: The Algorithm is Based on the Combination of Eight Risk Factors

Undisturbed sleep is associated with a noticeable unloading of the cardiovascular system. Physiological parameters derived from sleep have not yet been used for cardiovascular disease (CVD) risk assessment. However, data from sleep-related respiratory disturbances show a strong relation to cardiovascular morbidity and mortality. Hypoxaemia and muscle nerve sympathetic activity recorded during respiratory events (apnoeas, hypopnoeas) in sleeping OSA patients have been linked to the development of CVD.
The autonomic state indicator (ASI) algorithm calculates the cardiovascular risk from the combined value of the eight parameters. Each risk indicator can be analysed on its own. Table 1 contains a probable cause and recommendations for further treatment. The ASI algorithm has been implemented in an ambulatory sleep diagnostics system (SOMNObiocheck micro CARDIO®, Weinmann GmbH, Hamburg) (see Figure 2). The device is worn on the wrist overnight while the patient sleeps. The pulse wave and respiratory flow, registered via a pulse oximeter sensor, serve as the basis for computation of the cardiovascular risk. The patient’s risk profile is presented by the traffic light (red–amber–green) indicator (see Figure 2).

The report from the overnight recording provides a risk assessment of low, medium or high for sleep disturbance, sleep fragmentation, sleep apnoea and cardiovascular risk. In detail it reveals information about respiratory events (apnoea–hypopnoea index [AHI], respiratory disturbance index [RDI], snoring), oxygen saturation, heart rate and sleep fragmentation (autonomic arousal index [AAI]). A distinction between obstructive and central components can be made on the basis of respiratory disturbances. The device is suitable as a screening device for sleep-disordered breathing (SDB). Using a cut-off value of RDI >15/hour for sleep apnoea classification, a sensitivity of 96.2 % and a specificity of 91.7 % were achieved in cardiovascular risk assessment.

Furthermore, the absence of dipping of blood pressure and heart rate during sleep is associated with mortality. Nocturnal arterial vascular tone diagnosed by finger photoplethysmography is elevated in patients with essential hypertension.

Pulse Oximetry in the Determination of Cardiovascular Risk

Finger pulse oximetry is a non-invasive photometric technique principally known as a means of measuring oxyhaemoglobin saturation. A pulse oximeter uses pulsatile flow in the patient’s fingers to analyse multiple physiological parameters, including pulse wave and heart rate. These parameters provide information about the patient’s autonomic state and cardiovascular characteristics and indicate his or her cardiovascular risk. The core of the approach is analysis of the pulse wave. The photoplethysmographic pulse wave signal is collected with a sampling frequency of 50 Hz. In a second step the signal is filtered by a low-pass filter with a cut-off frequency of 10 Hz to remove noise.

Eight Parameters to Determine Risk Index

Cardiovascular risk is currently obtained from eight parameters whose signals are taken from the pulse wave recorded by the pulse oximeter. The parameters (see Figure 1, clockwise from top) are irregular pulse, reduced chronotropic response to desaturation (RCRD), low pulse rate variability, low pulse wave variability, brief pulse wave reflection time, periodic and symmetric desaturation, frequent desaturation and low basal saturation. They were derived from a beat-to-beat signal without averaging and were saved at a sampling rate of 5 Hz.

Table 1: Risk Indicators, their Pathophysiological Background and Treatment Recommendations

<table>
<thead>
<tr>
<th>Risk Indicator</th>
<th>Pathophysiological Background and Potential Aetiology</th>
<th>Treatment Recommendations</th>
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</thead>
<tbody>
<tr>
<td>1. Reduced chronotropic response to desaturation</td>
<td>Possible consequence of normal ageing. Possible sign of medication effect, existing coronary heart disease, diabetes mellitus or advanced respiratory disease</td>
<td>Check medication. Consider specific diagnostic procedures</td>
</tr>
<tr>
<td>2. Low pulse rate variability</td>
<td>Possible consequence of normal ageing. May be accompanied by autonomic neuropathy (e.g., diabetes, medication (β-blocker), coronary heart disease or hypertension</td>
<td>Check medication and clinical symptoms. Consider specific diagnostic procedures</td>
</tr>
<tr>
<td>3. Low pulse wave variability</td>
<td>Possible consequence of normal ageing. Possible sign of vascular disease (e.g., autonomic neuropathy, diabetes, advanced vascular disease) or effects of medication</td>
<td>Check medication and clinical symptoms. Consider more specific diagnostic procedures</td>
</tr>
<tr>
<td>4. Brief pulse wave reflection time</td>
<td>Possible consequence of normal ageing. Indicates elevated arterial stiffness (e.g., with high blood pressure, hyperlipidaemia, arteriosclerosis, PAOD)</td>
<td>Check clinical symptoms. Consider specific diagnostic procedures (e.g., for illnesses such as coronary heart disease or PAOD)</td>
</tr>
<tr>
<td>5. Periodic, symmetric desaturation</td>
<td>Specific desaturation pattern indicative of central respiratory disorder such as Cheyne–Stokes respiration</td>
<td>Check disease-specific symptoms such as heart and central nervous system function. Consider specific diagnostic procedures (sleep diagnostics)</td>
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<tr>
<td>6. Frequent desaturation</td>
<td>Obstructive and/or central sleep apnoea, nocturnal hypoventilation, advanced lung disease, respiratory insufficiency</td>
<td>Check specific clinical symptoms. Consider specific diagnostic procedures (sleep diagnostics, pulmonary function, blood gas analysis)</td>
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<tr>
<td>7. Low basal saturation</td>
<td>Respiratory insufficiency caused by advanced lung disease (e.g., COPD, hypoxemia syndrome, severe sleep apnoea)</td>
<td>Check disease-specific symptoms. Consider specific diagnostic procedures (nocturnal polygraph, pulmonary function, blood gas analysis)</td>
</tr>
<tr>
<td>8. Irregular pulse</td>
<td>High probability of arrhythmia (e.g., atrial fibrillation, ventricular extrasystole), heart disease</td>
<td>Examine pulse wave signal for artefacts. Check disease-specific symptoms and heart function. Consider specific diagnostic procedures (cardiological diagnosis including ECG and/or long-term ECG)</td>
</tr>
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COPD = chronic obstructive pulmonary disease; ECG = electrocardiogram; PAOD = peripheral arterial occlusive disease.
In a recent multicentre follow-up study with 327 patients examined, the computed risk index based on this new method was “significantly associated” with other risk scores such as the ESH/ESC Score, Framingham, EU Score and PROCAM. Nocturnal pulse wave recording provides novel insights into cardiovascular risk assessment.

**Autonomic State Indicator Algorithm Derived from Photoplethysmographic Signal – Compass Function for Diagnosis and Possible Additional Therapeutic Steps**

Beyond a simple screening for SDB, the algorithm based on the pulse wave signal offers an assessment of cardiovascular risk. From the results of an overnight recording, the treating physician obtains information about decisive physiological parameters for use in evaluating the patient and planning further medical treatment. Outside the sleep laboratory, the device can be put to use in all medical specialties which require a fast and reliable assessment of the patient’s cardiovascular risk.

Prevention is at the heart of using the ASI. Based on scientific and clinical data, the ASI was developed to help doctors assess patients’ cardiovascular risk, to detect potential, incipient and existing serious consequences to SDB patients and to make decisions regarding treatment. Further studies should show whether night-to-night variability and drug treatment could affect the ASI classification outcome.