PSD Graph

The HRV spectral analysis of ECG signal
‘BURN-OUT’ syndrome, chronic fatigue, sleep disorders and their diagnostics using the PSD graph

The ‘burn-out’ syndrome significantly threatens mainly the young generation of the society nowadays. Its increasing prevalence in various forms accompanied by chronic fatigue, sleep disorders and everyday exhaustion calls for new diagnostic possibilities. The PSD graph from BTL CardioPoint Holter system presents a simple and comprehensible way of parallel interpretation of the autonomous nerve activity at a specific time using HRV (Heart Rate Variability). At the same time, it is a graphic visualisation of patient’s degree of adaptability in situations involving physical or mental strain and stress. This method has its application in the field of clinical medicine to set the right therapy and to modify lifestyle as well as in the field of sports medicine to detect overtraining syndrome.

Autonomous cardiovascular regulation

Heart activity is regulated by the autonomic nervous system (ANS) with high sensitivity. It is independent of conscious control and works on its own not depending on higher nerve control. Sympathetic and parasympathetic divisions play a vital role in this regulation as they cooperate together in a dynamic equilibrium.

PARASYMPATHETIC DIVISION (N. vagus)

The parasympathetic nervous system (PSNS) provides rest mode for our body. N. vagus visceromotor fibres lower heart frequency and heart contractility. They usually lower also contractility of coronary arteries. They slow down the atrioventricular transmission and overall lower myocardial excitability. Apart from the cardiovascular regulation, it enhances the activity of digestive and excretory system and inhibits the activity of muscular and respiratory system. It contributes to efficient digestion, rest and organism regeneration.

SYMPATHETIC DIVISION (Nn. cardiaci)

The sympathetic nervous system (SNS) is activated mainly in time of physical strain and in stressful situations. The influence of sympathetic division increases heart rate and heart contraction intensity. It speeds up the atrioventricular transmission and increases myocardial excitability. Apart from cardiovascular regulation, it increases breathing frequency and muscular system activity. It increases overall organism power during fight or flight response behaviour.
The importance of HRV analysis

One of the characteristics of heart regulation is that it is not constant. It changes beat to beat and adjusts its activity to current needs of an organism. As a result, Heart Rate Variability (HRV) reflects not only regulation mechanisms, but also influence of many factors - inheritance, age, sex, physical fitness as well as individual's mental state. The heart-rate regulation is almost entirely nervous. The sinoatrial node (SA), which is normally responsible for heart rate, is under constant tonic influence of ANS. Increased sympathetic tonus speeds up heart rate, increased parasympathetic tonus, slows it down. HRV is shown as a change in RR intervals length in normal sinus rhythm.

The HRV analysis is based on evaluation of intervals fluctuation between normal consecutive contractions. The primary information source for the HRV analysis is a usual ECG record. It is necessary to be particular about absence of abnormal contractions. The BTL CardioPoint (ECG evaluation computer software) leaves out ectopic contractions and other artefacts and does not use them for the analysis.

**Sinus rhythm** - normal HRV, normal change in RR interval length

| TF 72 | 820 | 830 | 830 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 | 820 |
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|       | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   |

**Sinus rhythm** - lower HRV, very small changes in RR interval length, patient's heart 'works' as a metronome

| TF 92 | 650 | 654 | 652 | 652 | 656 | 654 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 | 656 |
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|       | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   | N   |

**Sinus arrhythmia** - significant changes in RR interval length

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Graphic examples of normal, low HRV and physiological sinus arrhythmia

Many authors describe HRV as a phenomenon that early and very sensitively reacts to the variation between health and disease. High HRV is a indicator of the good adaptability of the organism and is detected in a healthy person at rest with normal autonomic cardiovascular regulation. Reduced HRV is usually the hallmark of impaired organism adaptability and should lead to a more detailed diagnosis of its causes. Clinically is reduced HRV seen as an indicator of risk associated with the development of cardiovascular or metabolic diseases.
HRV – ANS association

The sympathetic ANS division usually prevails during physical activity or in stressful situations. It is accompanied by an increased heart rate (HR) along with lower HRV.

The parasympathetic ANS division is used mainly during rest state, sleep and general organism regeneration, in which it associates with breathing frequency. It is accompanied by a lower HR and increased HRV. The previously mentioned permanently lower HRV could be a sign of health problems.

From an ECG record to the PSD graph

Routine HRV analysis nowadays enables to quickly, simply and noninvasively quantify autonomous regulation. Using the so-called spectral decomposition, it is possible to evaluate the proportions of both main divisions – the sympathetic and the parasympathetic. The pictures below describe the process of obtaining the PSD graph from an ECG signal in a simple „step by step“ way.

1. In a first step, measure the different length of RR intervals

2. Plot the measured RR intervals one by one into a bar graph, in which y-axis represents the RR interval length.

3. Connect all the peaks of all the bars and you consequently receive a curve for further analysis (see next paragraph).
4. The basis of the spectral analysis is splitting irregular HRV data (the curve from previous paragraph) into regular cycles representing the HRV fluctuation. The sympathetic and the parasympathetic divisions ‘work’ reciprocally with different frequencies. The parasympathetic division ‘reacts’ faster, while the sympathetic division more slowly in relation to different characteristics of their mediators (neurotransmitters). Based on this, it is possible to statistically and mathematically distinguish and quantify the so-called spectral power of both ANS divisions. Simply said, the spectral analysis can be compared to light beam being split using a prism. By splitting it, we receive lights of various colours and wavelengths. Spectral analysis method (Fourier transform, FT) splits the input signal (the curve from previous paragraph) into a sum of periodic functions with various frequencies and amplitudes. In conclusion, the PSD graph is created as a result of HRV spectral analysis and it is a sort of its graphic interpretation.

Respective RR intervals are transformed into zones with different frequencies using the FT. The HRV frequency spectrum has three basic zones:

- **HF (high frequency zone)** - in the frequency range of 0.15 – 0.40 Hz. This range defines activity and fast changes of the ANS parasympathetic.
- **LF (low frequency zone)** - in the frequency range of 0.04 – 0.15 Hz. This range defines activity and slow changes of the ANS sympathetic (with a partial parasympathetic activity).
- **VLF (very low frequency zone)** - very low-frequency range of 0.01 – 0.04 Hz. This range indicates chemoreceptor and renin-angiotensin system activity.

The PSD graph consists of the X-axis, which shows time, and the Y-axis, which shows frequency range. ANS divisions activity is represented by colours, which are ranging from light shades of green, yellow and red to their dark shades. Frequency ‘power’ in a specific range and time increases with colour intensity and density as follows:

- dark green – minimal activity of a specific ANS division
- yellow – increasing activity of a specific ANS division
- red to dark red – strong activity of a specific ANS division
How to simply evaluate a PSD graph

For example: a woman, aged 25, healthy

1. INTERACTIVE HR GRAPH / PATIENT’S ACTIVITY GRAPH

We follow the changes of heart rate (HR) related to patient’s activity during the day and at night. We observe normal heart rate (green colour) in the evening and at night during sleep (9PM-9AM). We observe a higher HR connected to patient’s physical activity (red colour) during the day (10-11.30AM and 5-8PM).

2. TACHOGRAPH – A GRAPH SHOWING HRV ANALYSIS IN TIME

We observe normal Heart Rate Variability (HRV) in the tachograph in the evening / at night. During the day, in the morning (10-11.30AM) and in the afternoon (5-7PM) we observe lower HRV due to increasing HR, which is probably related to patient’s physical activity.

3. GRAPH – HRV SPECTRAL ANALYSIS

It is important to primarily follow sympathetic activity in the LF range in the PSD graph. Its strong activity confirms high organism adaptability during the day, i.e. the patient shows viability and stamina. Secondarily, we evaluate parasympathetic activity in the HF range and the so-called patient’s regeneration potential, which keeps equilibrium between both divisions of the ANS during rest and sleep time.
In this example of normal HRV spectral analysis we are able to observe overall high spectral power in the PSD graph. We observe normal sympathetic activity during the day (LF range) and a relative dominance of the parasympathetic at night (9PM-10AM, good regeneration potential of the patient). From 5.00 to 5.40PM, it is seen a decrease in spectral power in all frequency ranges – HF, LF and VLF. This image is typical for patient’s physical activity accompanied by an increase in HR and a decrease in HRV.

Clinical interpretation of ANS sympathetic and parasympathetic activity

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<th>Frequency range (Hz)</th>
<th>ANS active division</th>
<th>Clinical interpretation*</th>
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| **HF 0.40 – 0.15**   | Parasympathetic (n.vagus activity connected to respiration arrhythmia) | Increased activity (red colour shades)  
  • higher physiological activity while sleeping (with healthy individuals and athletes)  
  • rest and regeneration  
  • respiration arrhythmia and hyperventilation  
  **Decreased activity (green colour shades)**  
  • lower physiological activity during the day  
  • decreased electric heart stability, chronic stress  
  • cardiovascular and digestion disorders  
  • physical strain, training |
| **LF 0.15 – 0.04**   | Sympathetic (with partial parasympathetic activity) (reflects sympathetic and parasympathetic ANS division activity at the same time and relative vasomotor centre activity level) | Increased activity (red colour shades)  
  • higher physiological activity during the day  
  • physical and mental stress  
  • orthostatic strain  
  **Decreased activity (green colour shades)**  
  • lower physiological activity during sleep (with healthy individuals), fatigue, lower amount of energy, sleep disorders, lethargy, carelessness |
| **VLF 0.04 – 0.0033** | Humoral and metabolic sinoatrial node regulation (circulating catecholamines, thermoreceptor/chemoreceptor activity, renin angiotensin system activity,...) | Increased activity (red colour shades)  
  • hyperadaptive state  
  **Decreased activity (green colour shades)**  
  • energy deficit  
  • adaptive mechanisms failure |

*The HR is not isolated but instead is closely related to regulation of blood pressure, respiration and other factors. The results of the analysis of HRV must therefore be interpreted in the context of the overall clinical condition of the patient and therapy. ANS divisions activity evaluation requires determining whether physiological or pathological increase / decrease at the given time period (day / night) is concerned.*
Illustrative examples

A man, aged 50

The general spectrum power is average. Sympathetic activity in the LF range is normal during the day. We observe relatively higher proportion of high-frequency waves power of the HF range and dominance of the parasympathetic division. The patient shows a good regeneration potential at night.

Patient’s physical activity from 8PM to 9PM is accompanied by a higher HR and lower HRV. We observe a significant physiological spectral power decrease in all frequency ranges – HF, LF and VLF.

A man, aged 50, ‘burn-out’ syndrome

We observe a reduced overall spectral power in all frequency ranges - HF, LF and VLF. Both sympathetic and parasympathetic activity are minimal. There is insufficient regeneration potential at night. Between 1AM and 4AM we observe an increase in VLF range activity. There is generally visible overall ANS exhaustion and weak cardiovascular-system immunity to stress. It is not possible to expect fast reverse dynamics of these changes. There is low chance of quick recovery.

A man, aged 50

Patient’s spectral power is lower during the day in frequency ranges - HF, LF. Reduced sympathetic activity is visible in the LF range during the day and it significantly increases at night and in the early morning.
HRV and ANS association provides perspective possibilities of PSD graph usage even in terms of sport diagnostical to achieve higher sport accomplishments. Specifically, it helps to:

- identify (in)sufficient regeneration,
- identify possible overtraining syndrome,
- identify training processes dynamics in order to optimise them,
- identify periods when an athlete is more susceptible to an illness/an injury,
- identify the degree of individual adaptation to physical strain,
- screen physically prepared and perspective athletes,
- screen people to whom some kind of sport poses a risk

A man, aged 16, an athlete

Overall spectrum power is high with average relative dominance of high-frequency (HF) waves and higher parasympathetic activity. The patient shows good quality regeneration potential while sleeping.
A man, aged 18, an athlete, ‘overtraining syndrome’

In this particular case we observe:
Overall spectrum power is slightly lower during the day (significant low-frequency waves reduction with dominance of high-frequency waves). We observe a significant increase of overall spectral power and evidently higher activity of both ANS divisions in the night.

With this athlete, the PSD graph enables us to expect ‘overtraining syndrome’ with signs of sympathetic division cessation during the day (while training), sympathetic hyperactivity at night (it is necessary to take possible orthostatic strain into account) and weak regeneration potential. It is important for a trainer to detect reasons for athlete’s particular state and to optimise their training programme in time. Common ‘overtraining’ symptoms include: overall decreased sympathetic activity, energy loss, chronic fatigue, sleep disorders and doziness during the day.

Summary

The Power Spectral Density graph in the BTL CardioPoint Holter system represents a simple and comprehensible way of the autonomous nerve activity interpretation using HRV analysis. Consequently, it visualizes the patient’s degree of adaptability to situations involving physical or mental strain and stress. The complete record can be reviewed at once, therefore the PSD graph provides a fast and simple overview of the patient’s health condition.
LITERATURE


2 Dekker JM, Crow RS, Folsom AR et al: Disease and mortality from several causes: The ARIC study. Circulation, 2000;102:1239-1244. doi: 10.1161/01.CIR.102.11.1239


The BTL CardioPoint® is a versatile software solution integrating ECG, Stress test, Holter, ABPM and Spirometry into one unified platform with one patient database and the same logic of controls for each module. The software has a fully customizable interface, and its layout and work steps can be easily adapted. The operator is allowed to arbitrarily add or move tables, ECG strips and other windows. Fast and intuitive work is ensured by an ergonomically optimized user interface with shortened mouse tracks and hotkeys. Colour schemes are designed for both dark and light ambience. The BTL CardioPoint® can be used as a stand-alone cardiology system, or it can be seamlessly integrated into an existing ambulatory or hospital system. The BTL CardioPoint® is software that adapts to the user, instead of the user having to adapt to the software.