IJAYUSH
International Journal of AYUSH
AYURVEDA • YOGA • UNANI • SIDDHA • HOMEOPATHY
https://internationaljournal.org.in/journal/index.php/ijayush/
ISSN: 2349-7025
OPEN ACCESS
★ PEER REVIEWED ★
MONTHLY

| Review Article | Volume 15 Issue 06 | June 2026 |
|---|---|---|

# RMSSD AND SDNN AS IMPORTANT MARKERS OF CARDIAC AUTONOMIC REGULATION: A COMPREHENSIVE REVIEW

**[1]Dr. Lokesh and [2]Dr. Devendra Khurana**

[1]PhD Scholar, Department of Kriya Sharir, Institute for Ayurved Studies and Research, Shri Krishna Ayush University, Kurukshetra, Haryana, India.

[2]Principal and Professor, Department of Kriya Sharir, Sanskaram Ayurvedic Medical College and Hospital, Jhajjar Haryana, India.

## Abstract

Heart Rate Variability (HRV) is a non-invasive physiological measure that reflects variations in the time intervals between successive normal heartbeats and provides valuable information about cardiac autonomic regulation. Among the various methods of HRV assessment, time-domain analysis is widely used because of its simplicity, accessibility and clinical relevance. Standard Deviation of NN intervals (SDNN) and Root Mean Square of Successive Differences (RMSSD) are two important time-domain parameters frequently employed in physiological and clinical research. SDNN represents the overall variability of normal-to-normal intervals within a defined recording period, whereas RMSSD primarily reflects short-term variations associated with parasympathetic cardiac modulation. This review aims to explore the physiological basis, calculation methods, interpretation and clinical significance of these two important HRV indices. It also discusses the influence of age, gender, physical activity, sleep, psychological stress, respiration and environmental conditions on RMSSD and SDNN. Their applications in cardiovascular health assessment, autonomic dysfunction, stress monitoring, metabolic disorders and preventive healthcare are also highlighted. Furthermore, the review examines the importance of recording duration, standardization of measurement techniques and appropriate interpretation of HRV parameters in clinical practice. Understanding the complementary roles of SDNN and RMSSD may improve the interpretation of cardiac autonomic function and support their application in clinical research, preventive medicine and personalized healthcare.

**Keywords-**Heart Rate Variability, RMSSD, SDNN, Time-Domain Analysis, Cardiac Autonomic Regulation, Parasympathetic Activity

## 1. INTRODUCTION

Heart Rate Variability (HRV) refers to the natural variation in the time interval between successive heartbeats. It is an important physiological measure used to understand the functioning of the cardiovascular system and its autonomic regulation. Although heart rate indicates the number of heartbeats per minute, HRV describes the variation in the time intervals between individual heartbeats. These variations occur due to the continuous interaction of the sympathetic and parasympathetic divisions of the autonomic nervous system. HRV is widely used as a non-invasive tool for evaluating cardiac autonomic function and studying physiological adaptation to internal and external stimuli. [1]

The autonomic nervous system plays an essential role in maintaining cardiovascular homeostasis by regulating heart rate, cardiac rhythm and other circulatory functions. The sympathetic nervous system generally increases heart rate, whereas parasympathetic activity, mainly mediated through the vagus nerve, decreases heart rate. Both divisions continuously influence the sinoatrial node, producing variations in the intervals between successive normal heartbeats. These variations are also influenced by respiration, baroreceptor activity, physical activity, emotional stress and environmental conditions. Therefore, HRV provides useful information about the dynamic regulation of cardiac function rather than simply measuring the resting heart rate. [2]

Time-domain analysis is one of the basic methods used to quantify HRV. It evaluates the variation in normal-to-normal (NN) intervals over a specified recording period. Among its different parameters, Standard Deviation of NN intervals (SDNN) and Root Mean Square of Successive Differences (RMSSD) are particularly important. SDNN represents the overall variability of NN intervals during the recording period, whereas RMSSD measures short-term beat-to-beat variations and is predominantly associated with parasympathetic cardiac modulation. Both parameters provide complementary information about cardiac autonomic regulation and are widely used in physiological and clinical investigations. [3]

The clinical interpretation of RMSSD and SDNN requires an understanding of their calculation, physiological significance and recording conditions. SDNN is influenced by the duration of ECG recording because longer recordings capture a wider range of physiological variations. RMSSD is generally considered a useful index for assessing short-term cardiac vagal modulation. However, neither parameter should be interpreted independently of factors such as age, gender, respiration, body posture, physical activity and psychological state. Standardization of ECG recording and appropriate processing of NN intervals are therefore essential for obtaining reliable and comparable results. [4]

Despite the increasing use of HRV in cardiovascular and physiological research, differences in measurement techniques and interpretation may affect the comparability of findings. A clear understanding of SDNN and RMSSD is necessary for their appropriate application in clinical assessment, preventive healthcare and research. Therefore, the present review focuses on the physiological basis, calculation methods, interpretation and clinical applications of these two important time-domain HRV parameters. It also highlights their complementary roles and the methodological considerations required for accurate assessment of cardiac autonomic regulation.

## 2. PHYSIOLOGICAL BASIS OF HEART RATE VARIABILITY

### 2.1 Role of the Autonomic Nervous System in Heart Rate Regulation

The autonomic nervous system (ANS) plays an important role in controlling heart rate and maintaining cardiovascular homeostasis. It consists of two major divisions: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). These two systems continuously regulate the activity of the sinoatrial (SA) node, which acts as the natural pacemaker of the heart. Their combined influence produces continuous variations in the intervals between successive heartbeats. The sympathetic nervous system generally increases heart rate by stimulating cardiac beta-1 adrenergic receptors, whereas parasympathetic activity decreases heart rate mainly through the vagus nerve. The balance and interaction between these systems contribute to the pattern of HRV observed during ECG recording. [5]

The sympathetic and parasympathetic systems do not always act in a simple reciprocal manner. Their activity may change independently or simultaneously according to physiological requirements. For example, during physical exercise, sympathetic activity increases while parasympathetic influence is withdrawn, resulting in an increased heart rate. During rest and relaxation, parasympathetic influence generally becomes more prominent, contributing to a lower heart rate and greater beat-to-beat variation. Therefore, HRV reflects the dynamic modulation of cardiac rhythm by the autonomic nervous system rather than a direct measurement of sympathetic or parasympathetic nerve activity. [6]

### 2.2 Sympathetic Regulation of Cardiac Activity

The sympathetic nervous system influences cardiac activity through sympathetic nerve fibres and the release of noradrenaline. This neurotransmitter acts mainly on beta-1 adrenergic receptors present in the sinoatrial node and other cardiac tissues. Activation of these receptors increases the rate of spontaneous depolarisation of pacemaker cells, resulting in an increased heart rate. Sympathetic stimulation also increases myocardial contractility and conduction through the atrioventricular node. These responses prepare the cardiovascular system to meet increased physiological demands during exercise, physical stress and emotional stimulation. [7]

### 2.3 Parasympathetic Regulation of Cardiac Activity

The parasympathetic nervous system regulates cardiac activity mainly through the vagus nerve. Acetylcholine released from vagal nerve endings acts on muscarinic M2 receptors in the sinoatrial node, reducing the rate of spontaneous depolarisation and slowing the heart rate. Vagal influence is particularly important in regulating short-term variations in successive NN intervals. Since RMSSD reflects the magnitude of successive beat-to-beat differences, it is commonly used as an indicator of short-term cardiac vagal modulation under controlled recording conditions. [8]

### 2.4 Influence of Respiration on Heart Rate Variability

Respiration is an important physiological factor influencing HRV. During normal breathing, heart rate generally increases during inspiration and decreases during expiration. This phenomenon is known as respiratory sinus arrhythmia (RSA). During inspiration, cardiac vagal influence is temporarily reduced, leading to an increase in heart rate. During expiration, vagal influence increases, resulting in a decrease in heart rate. These respiratory-related changes contribute significantly to short-term variations in NN intervals and are particularly relevant to the interpretation of RMSSD. The magnitude of respiratory sinus arrhythmia is also influenced by respiratory rate, breathing depth and individual physiological conditions. [9]

### 2.5 Role of the Baroreceptor Reflex

The baroreceptor reflex is an important mechanism involved in maintaining blood pressure and cardiovascular stability. Baroreceptors are pressure-sensitive receptors located mainly in the carotid sinus and aortic arch. They detect changes in arterial blood pressure and send sensory information to the cardiovascular regulatory centres in the brainstem. When blood pressure increases, baroreceptor activity increases, producing greater parasympathetic influence and reduced sympathetic activity. This results in a reduction in heart rate. Conversely, when blood pressure decreases, sympathetic activity increases and parasympathetic influence decreases, resulting in an increased heart rate. Through this continuous feedback mechanism, the baroreceptor reflex contributes to short-term cardiovascular regulation and influences HRV. [10]

## 3. TIME-DOMAIN ANALYSIS OF HEART RATE VARIABILITY

### 3.1 Definition and Principle of Time-Domain Analysis

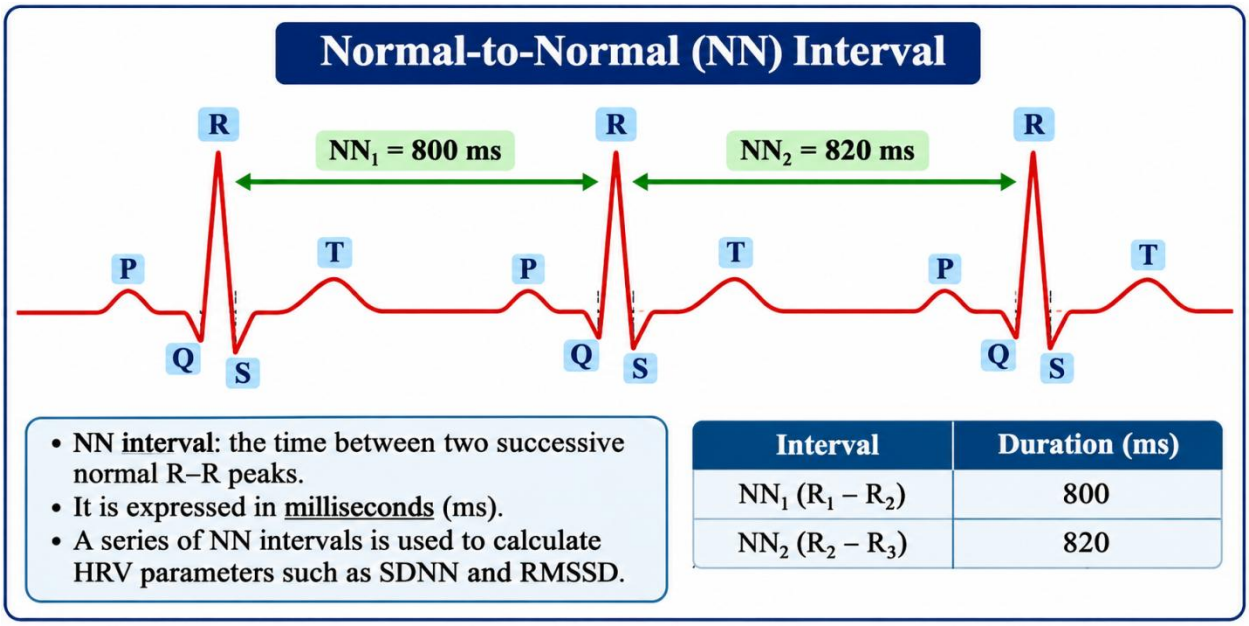
Time-domain analysis is one of the simplest and most commonly used methods for evaluating Heart Rate Variability (HRV). It involves measuring the time intervals between successive normal heartbeats and calculating statistical values to determine the degree of variation. These intervals are known as normal-to-normal (NN) intervals, representing the time between consecutive normal sinus beats after excluding abnormal or ectopic beats. The analysis is

generally performed using ECG recordings, in which the R waves of successive cardiac cycles are identified and the intervals between them are measured in milliseconds. The calculated values provide information about the variability of cardiac rhythm during a particular recording period. [11]

The basic principle of time-domain analysis is that the intervals between successive normal heartbeats are not perfectly equal, even under resting conditions. These differences occur due to continuous autonomic regulation, respiration and other physiological influences. Statistical calculations are applied to the recorded NN intervals to quantify both overall variability and short-term beat-to-beat changes. The results are generally expressed in milliseconds (ms), except for certain parameters such as pNN50, which is expressed as a percentage. Time-domain analysis is particularly useful because it does not require complex frequency-based signal processing. [12]

### 3.2 Measurement of Normal-to-Normal (NN) Intervals

NN intervals are the time intervals between consecutive normal sinus beats. They are derived from ECG recordings by identifying the R peaks of successive QRS complexes. The interval between two consecutive R peaks is initially called the RR interval. However, not every RR interval necessarily represents a normal sinus beat. Abnormal beats, ectopic beats, missed detections and signal artefacts may influence the measured intervals and produce misleading HRV values. Therefore, appropriate identification and correction of abnormal or erroneous beats are important before calculating time-domain parameters. [13]




The NN interval series forms the basic dataset for time-domain HRV analysis. For example, if the successive NN intervals are 800 ms, 820 ms, 790 ms and 810 ms, the differences between these intervals represent beat-to-beat variations. Statistical measures calculated from the complete

series help determine the magnitude and pattern of cardiac variability. Accurate ECG recording, reliable R-peak detection and appropriate artefact handling are essential for obtaining meaningful results.

### 3.3 Classification of Time-Domain HRV Parameters

Time-domain HRV parameters are broadly classified into statistical measures based on the NN intervals and measures calculated from successive differences between adjacent NN intervals. These parameters provide different information regarding cardiac rhythm variability. The Standard Deviation of NN intervals (SDNN) and Root Mean Square of Successive Differences (RMSSD) are among the most widely used parameters in clinical and physiological research. Other commonly described parameters include SDANN, SDNN index, NN50 and pNN50. [14]

### 3.4 Common Time-Domain HRV Parameters

Different time-domain parameters are used to assess the variability of NN intervals. Some parameters describe the overall variation in heart periods, whereas others measure the differences between consecutive heartbeats. SDNN and RMSSD are particularly important because they provide complementary information about cardiac rhythm variability. Other parameters, such as SDANN and SDNN index, are mainly used in long-term recordings. NN50 and pNN50 quantify the number and proportion of successive NN interval pairs that differ by more than 50 milliseconds. [15]

**Table 2. Commonly used time-domain parameters of HRV**

| Parameter | Full form | Description | Unit |
|---|---|---|---|
| SDNN | Standard Deviation of NN intervals | Overall variability of NN intervals during the recording | ms |
| RMSSD | Root Mean Square of Successive Differences | Short-term beat-to-beat variability | ms |
| SDANN | Standard Deviation of Average NN intervals | Variation between average NN intervals of successive 5-minute segments | ms |
| SDNN index | Mean of standard deviations of NN intervals | Average short-term variability across 5-minute segments | ms |

| | | | |
|---|---|---|---|
| NN50 | Number of NN50 pairs | Number of successive NN interval pairs differing by more than 50 ms | Count |
| pNN50 | Percentage of NN50 pairs | Percentage of successive NN interval pairs differing by more than 50 ms | % |
| SDSD | Standard Deviation of Successive Differences | Standard deviation of differences between adjacent NN intervals | ms |

Source: Standard definitions of time-domain HRV measures.

### 3.5 Short-Term and Long-Term HRV Recordings

The duration of ECG recording is an important consideration in time-domain HRV analysis. HRV values are influenced by the length of the recording because different recording periods capture different physiological variations. Short-term recordings are generally performed over five minutes under controlled and relatively stable conditions. They are commonly used in physiological studies to evaluate resting cardiac autonomic modulation. Long-term recordings are usually obtained over 24 hours using ambulatory ECG or Holter monitoring and provide information about cardiac variability during different activities, sleep and wakefulness. [16]

Five-minute recordings are particularly useful for studying short-term HRV parameters such as RMSSD and SDNN. However, the values obtained from a five-minute recording should not be directly compared with those obtained from a 24-hour recording because the two durations represent different physiological conditions and periods of observation. SDNN is especially dependent on recording duration, as longer recordings include additional sources of variation. Therefore, recording duration should always be clearly mentioned when reporting HRV results. [17]

### 3.6 Importance of Standardization in Time-Domain Analysis

For reliable HRV assessment, ECG recordings should be obtained under standardized conditions. Factors such as body posture, time of measurement, physical activity before recording, breathing pattern and environmental conditions should be considered. The same recording duration and measurement procedures should preferably be maintained when comparing HRV values between individuals or different study visits. Proper identification of NN intervals and removal or correction of artefacts are also necessary to minimize measurement errors. These precautions improve the reliability, reproducibility and interpretation of time-domain HRV parameters.

## 4. ROOT MEAN SQUARE OF SUCCESSIVE DIFFERENCES (RMSSD)

### 4.1 Definition and Concept of RMSSD

Root Mean Square of Successive Differences (RMSSD) is an important time-domain parameter of Heart Rate Variability (HRV) used to assess short-term variations between successive normal-to-normal (NN) intervals. It measures the magnitude of beat-to-beat differences by calculating the square root of the average of squared differences between consecutive NN intervals. RMSSD is generally expressed in milliseconds (ms) and is commonly used in short-term ECG recordings for evaluating cardiac autonomic modulation. It is particularly sensitive to rapid changes in heart period associated with parasympathetic influences on the sinoatrial node. [18]

RMSSD primarily reflects short-term cardiac variability mediated by the parasympathetic nervous system, particularly vagal modulation. Unlike SDNN, which represents the overall variability of NN intervals during a recording period, RMSSD focuses on changes between consecutive intervals. Therefore, it is considered a useful parameter for studying short-term cardiac autonomic regulation under resting and controlled conditions. However, RMSSD is not a direct measurement of vagal nerve activity and may also be influenced by respiration, mean heart rate, recording conditions and individual physiological characteristics. [19]

### 4.2 Mathematical Formula and Calculation of RMSSD

RMSSD is calculated by determining the differences between successive NN intervals, squaring each difference, calculating the mean of these squared differences and finally obtaining the square root of the result. This method gives greater importance to larger successive differences because the differences are squared before averaging. The final value represents the magnitude of short-term variation between consecutive normal heart periods. [20]

The mathematical formula for calculating RMSSD is:

$$RMSSD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N-1}(NN_{i+1} - NN_i)^2}$$

Where:

- **$NN_i$:** Duration of the current normal-to-normal interval.
- **$NN_{i+1}$:** Duration of the next normal-to-normal interval.
- **N:** Total number of valid NN intervals.
- **RMSSD:** Root mean square of successive differences, expressed in milliseconds.

### Example of RMSSD calculation

Consider the following five successive NN intervals:

| Beat number | NN interval (ms) | Successive difference (ms) | Squared difference ($ms^2$) |
|---|---|---|---|
| 1 | 800 | — | — |
| 2 | 820 | +20 | 400 |
| 3 | 790 | −30 | 900 |
| 4 | 810 | +20 | 400 |
| 5 | 800 | −10 | 100 |
| **Total** | — | — | **1800** |

$$RMSSD = \sqrt{\frac{1800}{4}}$$

$$RMSSD = \sqrt{450} = 21.21\ ms$$

Thus, the RMSSD value in this example is approximately **21.21 ms**.

This is an illustrative calculation using five NN intervals, not a clinical reference value.

### 4.3 Physiological Significance of RMSSD

RMSSD provides information about rapid changes in cardiac rhythm and is particularly useful for assessing short-term autonomic modulation. Its physiological significance is mainly related to parasympathetic influence on the sinoatrial node. The vagus nerve can rapidly modify the timing of successive heartbeats through the release of acetylcholine, producing beat-to-beat variations in NN intervals. These rapid changes are reflected in RMSSD values. Consequently, RMSSD is frequently used in physiological studies to assess cardiac vagal modulation during rest, exercise, recovery and psychological stress.[21]

A relatively higher RMSSD value generally indicates greater short-term beat-to-beat variability, whereas a lower value indicates reduced short-term variability under comparable measurement conditions. However, a higher RMSSD value should not automatically be interpreted as better cardiovascular health, nor should a lower value alone be considered evidence of autonomic dysfunction. Its interpretation requires consideration of age, heart rate, respiratory pattern, physical activity, health status and recording conditions. [22]

### 4.4 RMSSD and Parasympathetic Cardiac Modulation

Parasympathetic regulation is an important determinant of short-term HRV. The vagus nerve provides rapid inhibitory control over the sinoatrial node through acetylcholine-mediated activity. This mechanism allows the heart rate to change rapidly in response to respiration and other physiological requirements. RMSSD captures these rapid variations by measuring the differences between consecutive NN intervals. Therefore, it is commonly used as an indicator of vagally mediated cardiac variability in short-term recordings. [23]

Respiratory sinus arrhythmia contributes substantially to the variations measured by RMSSD. During inspiration, heart rate generally increases, while during expiration it decreases. These respiratory-related changes are largely mediated by fluctuations in cardiac vagal influence. However, the relationship between RMSSD and parasympathetic activity is also affected by breathing frequency, respiratory depth and prevailing heart period. Therefore, RMSSD should be interpreted as an indirect marker of cardiac vagal modulation rather than a direct measurement of parasym

pathetic nerve activity. [24]

### 4.5 Factors Influencing RMSSD

RMSSD is influenced by several physiological, psychological, lifestyle and environmental factors. These factors may produce variations in measurements even in healthy individuals. Therefore, their consideration is essential when comparing RMSSD values between individuals or across repeated assessments.

**Table 3. Major factors influencing RMSSD**

| Factor | Influence on RMSSD |
|---|---|
| **Age** | RMSSD generally decreases with advancing age |
| **Gender** | Differences may occur due to physiological and hormonal factors |
| **Physical activity** | Regular exercise may improve resting cardiac vagal modulation |
| **Sleep** | Sleep stage and sleep quality influence autonomic activity |
| **Psychological stress** | Acute stress commonly reduces vagally mediated HRV |

| | |
|---|---|
| **Respiration** | Breathing frequency and depth influence RMSSD |
| **Body posture** | Changes in posture alter autonomic cardiovascular regulation |
| **Heart rate** | Mean heart period influences the numerical value of RMSSD |
| **Environmental conditions** | Temperature and other environmental factors may affect HRV |

Age is an important determinant of RMSSD, as cardiac autonomic modulation generally changes with increasing age. Physical activity, sleep quality and psychological conditions may also influence its measurement. Acute psychological stress and strenuous physical activity can alter autonomic regulation, while recovery and relaxation may be associated with changes in cardiac vagal modulation. These variations highlight the importance of considering individual characteristics and measurement conditions during HRV assessment. [25]

### 4.6 Clinical Interpretation of RMSSD

RMSSD is increasingly used in clinical and physiological research because it provides a simple quantitative measure of short-term cardiac variability. It can help assess changes in cardiac autonomic modulation in individuals with different physiological and clinical conditions. A reduction in RMSSD may be observed in conditions associated with altered cardiac autonomic regulation, although it is not sufficient by itself to establish a clinical diagnosis. Similarly, an increase in RMSSD may indicate greater short-term cardiac variability but should always be interpreted in relation to the individual's baseline values and clinical condition. [26]

For appropriate interpretation, RMSSD should be assessed using standardized recording procedures and compared under similar conditions. Five-minute ECG recordings are commonly used for short-term assessment. It is also important to consider mean heart rate because HRV parameters, including RMSSD, are mathematically related to the prevailing heart period. Therefore, changes in RMSSD should not automatically be attributed to changes in parasympathetic activity without considering other physiological influences. [27]

### 4.7 Clinical and Research Applications of RMSSD

RMSSD has several applications in cardiovascular physiology, clinical research and preventive healthcare. Its ability to quantify short-term beat-to-beat variability makes it useful for investigating autonomic responses to different physiological and psychological conditions.

Major applications include:

1. **Cardiovascular health assessment:** RMSSD is used to study cardiac autonomic modulation and variations in cardiovascular regulation.

2. **Stress assessment:** It is used in psychophysiological research to investigate changes in cardiac vagal modulation associated with psychological stress.

3. **Exercise and recovery monitoring:** RMSSD is used to examine autonomic responses during physical training and recovery following exercise.

4. **Sleep research:** It helps investigate changes in cardiac autonomic modulation during different sleep stages and resting conditions.

5. **Metabolic and systemic disorders:** RMSSD is studied in conditions such as diabetes and other disorders associated with altered autonomic regulation.

6. **Preventive healthcare:** Repeated RMSSD measurements may help monitor individual physiological trends when obtained under standardized conditions. [28]

## 5. STANDARD DEVIATION OF NN INTERVALS (SDNN)

### 5.1 Definition and Concept of SDNN

Standard Deviation of Normal-to-Normal (NN) intervals (SDNN) is one of the most widely used time-domain parameters of Heart Rate Variability (HRV). It represents the statistical variation of all normal-to-normal intervals recorded during a specified ECG recording period. SDNN is calculated by determining the standard deviation of the NN intervals and is expressed in milliseconds (ms). It provides information about the overall variability of cardiac rhythm during the selected recording duration. Unlike RMSSD, which focuses on differences between successive NN intervals, SDNN considers the distribution of all NN intervals within the recording period. [29]

SDNN reflects the combined influence of different physiological mechanisms responsible for variations in heart rhythm. These include sympathetic and parasympathetic modulation, respiratory activity, baroreceptor reflexes and other regulatory processes operating during the recording period. In short-term recordings, SDNN primarily reflects variability occurring within that particular recording window. In long-term recordings, particularly 24-hour ECG monitoring, it also includes variations associated with sleep, physical activity, circadian rhythms and other daily physiological changes. Therefore, SDNN is considered an indicator of overall HRV rather than a specific measure of one autonomic division. [30]

### 5.2 Mathematical Formula and Calculation of SDNN

SDNN is calculated by measuring the standard deviation of all valid NN intervals obtained during an ECG recording. First, the mean of all NN intervals is calculated. Then, the difference between each NN interval and the mean is determined. These differences are squared and added together. The sum is divided by the appropriate number of observations, and the square root of the resulting value gives the SDNN. The calculation provides a quantitative measure of the dispersion of NN intervals around their mean value. [31]

The mathematical formula for SDNN is:

$$SDNN = \sqrt{\frac{\sum_{i=1}^{N}(NN_i - \overline{NN})^2}{N-1}}$$

Where:

- $NN_i$ = Individual normal-to-normal interval.
- $\overline{NN}$ = Mean of all NN intervals.
- $N$ = Total number of valid NN intervals.
- $SDNN$ = Standard deviation of NN intervals, expressed in milliseconds.

### Example of SDNN calculation

Consider the following five NN intervals:

| Beat number | NN interval (ms) | Deviation from mean (ms) | Squared deviation ($ms^2$) |
|---|---|---|---|
| 1 | 800 | −4 | 16 |
| 2 | 820 | +16 | 256 |
| 3 | 790 | −14 | 196 |
| 4 | 810 | +6 | 36 |
| 5 | 800 | −4 | 16 |
| **Total** | **4020** | **0** | **520** |

Mean NN interval:

$$\overline{NN} = \frac{4020}{5} = 804\ ms$$

SDNN:

$$SDNN = \sqrt{\frac{520}{5-1}}$$

$$SDNN = \sqrt{130} = 11.40\ ms$$

Thus, the SDNN value in this example is approximately **11.40 ms**.

This is an illustrative calculation using five observations and the sample standard deviation formula. It is not a clinical reference value.

### 5.3 Physiological Significance of SDNN

SDNN provides an estimate of the overall variability of NN intervals during a defined period of ECG recording. It reflects the combined effects of multiple physiological mechanisms that regulate cardiac rhythm. These mechanisms operate at different time scales and include autonomic nervous system activity, respiratory influences, blood pressure regulation and other cardiovascular control processes. Therefore, SDNN provides a broad assessment of cardiac rhythm variability rather than measuring a single physiological mechanism. [32]

A relatively higher SDNN indicates greater dispersion of NN intervals during the recording period, whereas a lower SDNN indicates reduced variability. However, these values must be interpreted according to the recording duration and physiological condition of the individual. For example, a five-minute resting ECG and a 24-hour Holter recording capture different components of cardiac variability. Consequently, SDNN values obtained from these two recording durations are not directly comparable. [33]

### 5.4 SDNN and Cardiac Autonomic Regulation

SDNN is influenced by both sympathetic and parasympathetic regulation of cardiac activity. These two divisions of the autonomic nervous system continuously modify the firing rate of the sinoatrial node and contribute to variations in successive NN intervals. Parasympathetic activity produces rapid changes in heart period, while sympathetic activity and other slower regulatory mechanisms contribute to variations over longer time scales. The relative contribution of these mechanisms depends on the duration and conditions of ECG recording. [34]

In short-term resting ECG recordings, SDNN is influenced considerably by parasympathetic modulation and respiratory-related variations. During longer recordings, additional influences such as physical activity, sleep–wake transitions, circadian rhythms and slower cardiovascular regulatory processes contribute to the overall SDNN value. Therefore, SDNN should not be considered a direct measurement of sympathetic activity or a simple indicator of sympathetic–parasympathetic balance.

### 5.5 Factors Influencing SDNN

SDNN is affected by several physiological, behavioural and environmental factors. These factors may influence cardiac autonomic regulation and produce variations in NN intervals. Their consideration is important when interpreting SDNN values in healthy individuals and patients.

**Table 4. Factors influencing SDNN**

| Factor | Influence on SDNN |
|---|---|
| **Age** | SDNN generally decreases with advancing age |
| **Gender** | Differences may occur due to physiological and hormonal variations |
| **Physical activity** | Exercise and physical fitness influence cardiac variability |
| **Sleep and circadian rhythm** | Sleep–wake transitions contribute to long-term variability |
| **Psychological stress** | Stress may alter autonomic cardiac regulation |
| **Respiratory pattern** | Breathing frequency and depth influence NN interval variability |
| **Cardiovascular diseases** | Altered cardiac autonomic regulation may reduce SDNN |
| **Metabolic disorders** | Diabetes and associated autonomic dysfunction may affect SDNN |
| **Medications** | Certain cardiovascular and other medicines influence HRV |
| **Recording duration** | Longer recordings generally produce greater SDNN values |

These factors demonstrate that SDNN is influenced by both individual characteristics and the conditions under which ECG recordings are obtained. In particular, recording duration is a major methodological consideration because SDNN represents the variability occurring throughout the complete observation period. [35]

### 5.6 Clinical Interpretation of SDNN

SDNN has considerable importance in cardiovascular research because reduced HRV has been associated with adverse cardiovascular outcomes. Early clinical investigations demonstrated that reduced 24-hour SDNN following acute myocardial infarction was associated with increased mortality. These findings established the importance of HRV assessment in cardiovascular risk evaluation, particularly among patients recovering from myocardial infarction. [36]

The Framingham Heart Study also investigated the relationship between reduced HRV and cardiovascular events in the general population. The findings demonstrated that reduced HRV was associated with an increased risk of subsequent cardiac events, supporting its potential role in cardiovascular risk assessment. However, SDNN should be interpreted together with clinical history, other cardiovascular parameters and appropriate recording information rather than being used as an independent diagnostic test. [37]

It is important to distinguish the interpretation of short-term SDNN from 24-hour SDNN. Clinical thresholds established from long-term Holter recordings should not be directly applied to five-minute ECG recordings. The numerical value of SDNN depends on recording duration, age, health status and measurement conditions.

### 5.7 Clinical and Research Applications of SDNN

SDNN is widely used in physiological and clinical research because it provides a quantitative assessment of overall cardiac rhythm variability. Its applications include:

1. **Cardiovascular risk assessment:** SDNN has been investigated as a prognostic marker in patients with cardiovascular diseases, particularly following myocardial infarction.

2. **Autonomic dysfunction:** It is used to study alterations in cardiac autonomic regulation associated with different clinical conditions.

3. **Diabetes mellitus:** SDNN is used in research investigating cardiovascular autonomic neuropathy and related complications.

4. **Exercise physiology:** It helps evaluate changes in cardiac variability associated with physical activity and recovery.

5. **Long-term cardiac monitoring:** Twenty-four-hour SDNN obtained through Holter monitoring provides information about cardiac variability during daily activities and sleep.

6. **Clinical research:** SDNN is used to compare cardiac variability across different populations, physiological conditions and research interventions.

A clinical study by Liu and colleagues evaluated time-domain HRV parameters in patients who had survived acute myocardial infarction. The study demonstrated the prognostic relevance of SDNN index in predicting cardiovascular and sudden cardiac death, highlighting the potential value of time-domain HRV measurements in long-term cardiovascular research. [38]

## DISCUSSION

Heart Rate Variability (HRV) is a useful non-invasive tool for assessing cardiac autonomic regulation. RMSSD and SDNN are important time-domain parameters that provide complementary information about cardiac rhythm variability.

RMSSD primarily reflects short-term beat-to-beat variations associated with parasympathetic modulation, whereas SDNN represents overall variability during a specified recording period. Both parameters are influenced by age, physical activity, sleep, stress, respiration and recording conditions.

Their applications include cardiovascular health assessment, autonomic function evaluation, exercise monitoring and preventive healthcare. However, proper interpretation requires standardized recording procedures, particularly regarding recording duration.

Overall, RMSSD and SDNN are valuable complementary markers for understanding cardiac autonomic regulation and supporting clinical and physiological research.

## CONCLUSION

Heart Rate Variability (HRV) is an important non-invasive measure for assessing cardiac autonomic regulation. Among the time-domain parameters, RMSSD and SDNN provide complementary information about cardiac rhythm variability. RMSSD primarily reflects short-term parasympathetic modulation, whereas SDNN represents overall variability during a specified recording period. Both parameters have significant applications in cardiovascular research, autonomic function assessment and preventive healthcare. Their accurate interpretation requires standardized recording procedures and consideration of individual physiological factors. Overall, RMSSD and SDNN are valuable tools for understanding cardiac autonomic function and may contribute to the development of personalized and preventive healthcare approaches.

## References


1. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation and clinical use. *Circulation*. 1996;93(5):1043–1065. doi:10.1161/01.CIR.93.5.1043.
2. Yilmaz, M., Kayancicek, H., & Cekici, Y. (2018). Heart rate variability: Highlights from hidden signals. *Journal of Integrative Cardiology*, *4*(5). https://doi.org/10.15761/jic.1000258
3. Laborde S, Mosley E, Thayer JF. Heart rate variability and cardiac vagal tone in psychophysiological research – recommendations for experiment planning, data analysis, and data reporting. *Front Psychol*. 2017;8:213. doi:10.3389/fpsyg.2017.00213.
4. Damoun N, Amekran Y, Taiek N, El Hangouche AJ. Heart rate variability measurement and influencing factors: towards the standardization of methodology. *Glob Cardiol Sci Pract*. 2024;2024(4):e202435. doi:10.21542/gcsp.2024.35.
5. Hafez OA, Chang RB. Regulation of cardiac function by the autonomic nervous system. *Physiology (Bethesda)*. 2025;40(3):258–270. doi:10.1152/physiol.00018.2024.
6. Johnston BW, Barrett-Jolley R, Krige A, Welters ID. Heart rate variability: Measurement and emerging use in critical care medicine. *J Intensive Care Soc*. 2020;21(2):148–157. doi:10.1177/1751143719853744.
7. Karim S, Chahal A, Khanji MY, Petersen SE, Somers VK. Autonomic cardiovascular control in health and disease. *Compr Physiol*. 2023;13(2):4493–4511. doi:10.1002/j.2040-4603.2023.tb00257.x.
8. Quigley KS, Gianaros PJ, Norman GJ, Jennings JR, Berntson GG, de Geus EJC. Publication guidelines for human heart rate and heart rate variability studies in psychophysiology — Part 1: Physiological underpinnings and foundations of measurement. *Psychophysiology*. 2024;61(9):e14604. doi:10.1111/psyp.14604.
9. Eckberg DL. The human respiratory gate. *J Physiol*. 2003;548(Pt 2):339–352. doi:10.1113/jphysiol.2002.037192.
10. Hainsworth R. The importance of the autonomic nervous system in the control of blood pressure. *Clin Auton Res*. 1998;8(5):285–291.

11. Catai AM, Pastre CM, de Godoy MF, da Silva E, Takahashi ACM, Vanderlei LCM. Heart rate variability: are you using it properly? Standardisation checklist of procedures. *Braz J Phys Ther*. 2020;24(2):91–102. doi:10.1016/j.bjpt.2019.02.006.

12. Nunan D, Sandercock GRH, Brodie DA. A quantitative systematic review of normal values for short-term heart rate variability in healthy adults. *Pacing Clin Electrophysiol*. 2010;33(11):1407–1417. doi:10.1111/j.1540-8159.2010.02841.x.

13. Peltola MA. Role of editing of R–R intervals in the analysis of heart rate variability. *Front Physiol*. 2012;3:148. doi:10.3389/fphys.2012.00148.

14. Sassi R, Cerutti S, Lombardi F, et al. Advances in heart rate variability signal analysis: joint position statement by the e-Cardiology ESC Working Group and the European Heart Rhythm Association co-endorsed by the Asia Pacific Heart Rhythm Society. *Europace*. 2015;17(9):1341–1353. doi:10.1093/europace/euv015.

15. Cygankiewicz I, Zareba W. Heart rate variability. *Handb Clin Neurol*. 2013;117:379–393. doi:10.1016/B978-0-444-53491-0.00031-6.

16. Sammito S, Thielmann B, Klussmann A, Deußen A, Braumann KM, Böckelmann I. Guideline for the application of heart rate and heart rate variability in occupational medicine and occupational health science. *J Occup Med Toxicol*. 2024;19:15. doi:10.1186/s12995-024-00414-9.

17. Pecchia L, Castaldo R, Montesinos L, Melillo P. Are ultra-short heart rate variability features good surrogates of short-term ones? State-of-the-art review and recommendations. *Healthc Technol Lett*. 2018;5(3):94–100. doi:10.1049/htl.2017.0090.

18. Penttilä J, Helminen A, Jartti T, Kuusela T, Huikuri HV, Tulppo MP, et al. Time domain, geometrical and frequency domain analysis of cardiac vagal outflow: effects of various respiratory patterns. *Clin Physiol*. 2001;21(3):365–376. doi:10.1046/j.1365-2281.2001.00337.x.

19. Berntson GG, Lozano DL, Chen YJ. Filter properties of root mean square successive difference (RMSSD) for heart rate. *Psychophysiology*. 2005;42(2):246–252. doi:10.1111/j.1469-8986.2005.00277.x.

20. Pham T, Lau ZJ, Chen SHA, Makowski D. Heart rate variability in psychology: a review of HRV indices and an analysis tutorial. *Sensors (Basel)*. 2021;21(12):3998. doi:10.3390/s21123998.

21. de Geus EJC, Gianaros PJ, Brindle RC, Jennings JR, Berntson GG. Should heart rate variability be "corrected" for heart rate? Biological, quantitative, and interpretive considerations. *Psychophysiology*. 2019;56(2):e13287. doi:10.1111/psyp.13287.

22. Koenig J, Thayer JF. Sex differences in healthy human heart rate variability: a meta-analysis. *Neurosci Biobehav Rev*. 2016;64:288–310. doi:10.1016/j.neubiorev.2016.03.007.

23. Umetani K, Singer DH, McCraty R, Atkinson M. Twenty-four hour time domain heart rate variability and heart rate: relations to age and gender over nine decades. *J Am Coll Cardiol*. 1998;31(3):593–601. doi:10.1016/S0735-1097(97)00554-8.

24. Cheshire WP, Freeman R, Gibbons CH, et al. Electrodiagnostic assessment of the autonomic nervous system: a consensus statement endorsed by the American Autonomic Society, American Academy of Neurology, and the International Federation of Clinical Neurophysiology. *Clin Neurophysiol*. 2021;132(2):666–682.

25. Grässler, B., Dordevic, M., Darius, S., Vogelmann, L., Herold, F., Langhans, C., Halfpaap, N., Böckelmann, I., Müller, N. G., & Hökelmann, A. (2021). Age-Related Differences in Cardiac Autonomic Control at Resting State and in Response to Mental Stress. *Diagnostics*, *11*(12), 2218. https://doi.org/10.3390/diagnostics11122218

26. Minarini, G. (2020). *Root Mean Square of the Successive Differences as Marker of the Parasympathetic System and Difference in the Outcome after ANS Stimulation*. Intechopen. https://doi.org/10.5772/intechopen.89827

27. de Geus EJC, Gianaros PJ, Brindle RC, Jennings JR, Berntson GG. Should heart rate variability be "corrected" for heart rate? Biological, quantitative, and interpretive considerations. *Psychophysiology*. 2019;56(2):e13287. doi:10.1111/psyp.13287.

28. Pham T, Lau ZJ, Chen SHA, Makowski D. Heart rate variability in psychology: a review of HRV indices and an analysis tutorial. *Sensors (Basel)*. 2021;21(12):3998. doi:10.3390/s21123998.

29. Shaffer F, McCraty R, Zerr CL. A healthy heart is not a metronome: an integrative review of the heart's anatomy and heart rate variability. *Front Psychol*. 2014;5:1040. doi:10.3389/fpsyg.2014.01040.

30. Maciejewska, K., Zaj\U0105C, C., Duch, K., Giza, M., & Masternak, A. (2026). Validation of the ultra short term heart rate variability measures under changing psychophysiological

state of the healthy participants at rest. *Scientific Reports*, *16*(1). https://doi.org/10.1038/s41598-026-55797-y

31. Pumprla J, Howorka K, Groves D, Chester M, Nolan J. Functional assessment of heart rate variability: physiological basis and practical applications. *Int J Cardiol*. 2002;84(1):1–14. doi:10.1016/S0167-5273(02)00057-8.

32. Munoz, M. L., Van Roon, A., Riese, H., Thio, C., Oostenbroek, E., Westrik, I., De Geus, E. J. C., Gansevoort, R., Lefrandt, J., Nolte, I. M., & Snieder, H. (2015). Validity of (Ultra-)Short Recordings for Heart Rate Variability Measurements. *PLoS ONE*, *10*(9), e0138921. https://doi.org/10.1371/journal.pone.0138921

33. Stein PK, Bosner MS, Kleiger RE, Conger BM. Heart rate variability: a measure of cardiac autonomic tone. *Am Heart J*. 1994;127(5):1376–1381. doi:10.1016/0002-8703(94)90059-0.

34. Kleiger RE, Miller JP, Bigger JT Jr, Moss AJ. Decreased heart rate variability and its association with increased mortality after acute myocardial infarction. *Am J Cardiol*. 1987;59(4):256–262. doi:10.1016/0002-9149(87)90795-8.

35. Tsuji H, Larson MG, Venditti FJ Jr, Manders ES, Evans JC, Feldman CL, et al. Impact of reduced heart rate variability on risk for cardiac events. The Framingham Heart Study. *Circulation*. 1996;94(11):2850–2855. doi:10.1161/01.CIR.94.11.2850.

36. Liu PY, Tsai WC, Lin LJ, Li YH, Chao TH, Tsai LM, et al. Time domain heart rate variability as a predictor of long-term prognosis after acute myocardial infarction. *J Formos Med Assoc*. 2003;102(7):474–479.

37. Gadaleta, M., Mason, F., Steinhubl, S. R., & Quer, G. (2023). Impact of comorbidities on heart rate variability in patients with high cardiovascular risk. *European Heart Journal*, *44*(Suppl 2). https://doi.org/10.1093/eurheartj/ehad655.3254

38. Liu, P. Y., Tsai, W. C., Lin, L. J., Li, Y. H., Chao, T. H., & Tsai, L. M. (2003). Time domain heart rate variability as a predictor of long-term prognosis after acute myocardial infarction. *Journal of the Formosan Medical Association, 102*(7), 474–479.