Arrhythmia Monitoring
ST/AR Algorithm
Application note

About this document
ST/AR (ST and Arrhythmia) is a multi-lead ECG algorithm designed for arrhythmia, ST Segment and QT Monitoring.

The ST/AR arrhythmia algorithm is indicated for use in instances where the clinician decides to monitor arrhythmias of adult, pediatric, and neonatal patients to gain information for treatment, to monitor adequacy of treatment, or to exclude causes of symptoms.

The intended use of the ST/AR arrhythmia algorithm is to monitor adult, pediatric, and neonatal patient’s ECG for heart rate, ventricular arrhythmias, atrial fibrillation (for adult patients) and produce events and alarms for one or two ECG leads. The ST/AR arrhythmia algorithm can monitor both paced and non-paced patients.

This application note describes:
- The ST/AR arrhythmia algorithm – filtering, detection and classification.
- Heart rate calculation.
- Arrhythmia monitoring for the paced patient.
- The arrhythmia system’s alarm structure.
- How to optimize computerized arrhythmia monitoring.

Depending on the device, not all described ST/AR features and functionalities may be available. See the relevant Instructions for Use for specific device information.

The assessment of the arrhythmia algorithm’s performance is described in a separate publication titled Assessing Arrhythmia Performance (part number 4522 991 12731).

Introduction
Computerized arrhythmia monitoring is a valuable clinical tool in many patient care areas. To be most effective, this tool requires a thorough knowledge of the system’s features, how the device processes the signals, and the proper application procedures. The ST/AR arrhythmia monitoring algorithm is designed to process one or two simultaneous channels of surface ECG signals for detecting changes in the ECG rhythm while offering continuous patient surveillance and alarm generation.
Through a sophisticated algorithm, QRS complexes are detected, labeled, and classified. Based on the classification, the device then generates alarms. It is the intent of this application note to explain the fundamentals involved in each of these steps.

**Arrhythmia monitoring algorithm**

An algorithm is a set of rules and instructions that devices use to analyze data. The arrhythmia monitoring algorithm processes the ECG signals for both paced and non-paced adult, pediatric, and neonatal patients. The algorithm performs several actions on the incoming ECG waveform, including filtering the signal, detecting the QRS, classifying the beat, calculating the heart rate, identifying ectopic events and rhythms, and generating alarms if necessary.

**Quality check of the ECG signal**

Before monitoring begins, the ECG signal quality is checked for noise and inoperative conditions.

**Noisy ECG signals**

Noise refers to any degradation of the ECG signal that makes it difficult to detect and classify beats accurately, thus affecting event detection and alarm generation. Causes of noise, such as artifact and electrical interference, should be avoided whenever possible.

The following are some possible causes of noisy ECG signals:

- Poor skin preparation
- Dried electrode gel
- Detached electrodes
- Broken lead wires
- Muscle artifact caused by shivering, movement, or tremors
- Baseline wander caused by excessive chest movement, or the offset differences between two brands of electrodes
- Respiration artifact caused by thoracic or abdominal movement of both spontaneous and ventilated breathing patterns
- Interference from equipment

Correcting any of the above ECG interferences increases the accuracy of the algorithm and decreases the incidence of false alarms. The causes of noisy signals and possible corrective actions are shown in Table 1.

**Inoperative conditions**

Inoperative conditions which interfere with or prevent monitoring the ECG signal can also interfere with arrhythmia monitoring. A leads off condition which results in the loss of ECG monitoring will also inhibit arrhythmia monitoring until the condition is corrected and the lead has been restored.

**Table 1 Noisy ECG problem solving**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
<th>Possible cause</th>
<th>What to do</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power line interference (50/60 Hz interference)</td>
<td>Regular sawtooth baseline with exactly 10 peaks every 5 mm at 25 mm/s (50 Hz) or 12 peaks every 5 mm at 25 mm/s (60 Hz)</td>
<td>Poor electrode placement. Possible non-grounded instrument near patient.</td>
<td>Reapply electrodes. Disconnect electrical appliances near patient (one at a time) by pulling wall plugs, to determine faulty grounding. Have engineer check grounding.</td>
</tr>
</tbody>
</table>

When using a 5-wire, 6-wire, or 10-wire lead set, a leads off condition does not necessarily result in the loss of monitoring. The arrhythmia algorithm will use whichever lead(s) are available for monitoring.

**Multi-lead monitoring**

While in most cases highly accurate results are obtained when monitoring two leads of ECG simultaneously, it is important to remember that both leads of ECG are being used for detection, classification, and alarm generation. The quality of both signals will affect the accuracy of the arrhythmia algorithm in beat detection, classification, and alarm generation.

Even though a multi-lead arrhythmia algorithm has better ability in handling noisy signals than a single-lead algorithm, in order to achieve the maximum performance it is important that the two ECG leads selected for monitoring be free of noise.

In the following example, the second lead is extremely noisy, and therefore it provides little value to QRS detection. During classification both leads are used. The second noisy lead may impact negatively on the final beat classification. In addition, if the channel 1 ECG becomes inoperative, the second lead will be the only lead available for analysis; hence poor performance will result.

![Figure 1 Two channel ECG](image)

Although the ST/AR algorithm has an improved handling of noisy signals and the changing amplitudes caused by the loss of a good lead, it is still important to choose the best two leads available. If there are false alarms, examine both leads. You may need to select a different lead or change the electrodes or electrode position if there is excessive noise, unstable voltage, low amplitude or large P- or T-waves. In cases where selecting a different lead or changing electrode position to correct the problem is not possible or practical, it is better to select a lead with the best signal quality and use single-lead analysis for monitoring.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
<th>Possible cause</th>
<th>What to do</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle artifact</td>
<td>Fuzzy, irregular baseline.</td>
<td>Tense, uncomfortable patient. Poor electrode placement. Tremors. Diaphoresis.</td>
<td>Make sure that the patient is comfortable. Check that electrodes are applied on flat, non-muscular areas of the torso; reapply electrodes if necessary.</td>
</tr>
<tr>
<td>Irregular baseline</td>
<td>Rough, jagged baseline.</td>
<td>Poor electrical contact. Respiratory interference. Faulty electrodes. Dry electrodes.</td>
<td>Reapply electrodes, using proper technique. Move electrodes away from areas with greatest movement during respiration. Apply new electrodes.</td>
</tr>
<tr>
<td>Baseline wander</td>
<td>Rhythmic up-and-down movement of the ECG baseline.</td>
<td>Movement of the patient. Improperly applied electrodes. Respiratory interference.</td>
<td>Make sure that the patient is comfortable. Reapply electrodes. Check that patient cable is not pulling on electrodes. Move electrodes away from areas with greatest movement during respiration.</td>
</tr>
<tr>
<td>Poor electrode contact</td>
<td>Trace switching from high to low in steps.</td>
<td>Loose electrodes. Defective cables.</td>
<td>Change all electrodes, using good skin preparation. Replace cables.</td>
</tr>
</tbody>
</table>

**ECG analysis**

**Step 1: ECG signal filtering**

**Digital sampling**

The patient’s incoming ECG waveforms are digitally sampled at up to 8000 samples/second. Once the pace pulses are detected, the ECG sampling rate of 500 samples/second is used to preserve the narrow pace pulses (spikes) for accurate pacing analysis. For QRS detection and ventricular fibrillation detection where high sampling rates are not needed, a lower sampling rate of 125 samples/second is used. For QRS classification, a sampling rate of 125 or 250 samples/second is used for analysis.

**Pace pulse processing**

A typical pace pulse consists of two components, a main pulse and a repolarization pulse. The main pulse, which is used to stimulate the heart, is characterized by its narrow width, sharp rise and fall, and large variation in amplitude. The repolarization pulse sometimes referred to as the pace pulse overshoot or the pace pulse tail, is used to deplete the charge built up between the heart and the pacemaker. The shape and the size of the pace pulse overshoot are a function of the energy content of the pace pulse and the amount of capacitive coupling. Pace pulse characteristics (including pulse amplitude, pulse duration, and size of overshoot) are specified in IEC 60601-2-27 section 20112.10113 and ANSI/AAMI EC13 section 4.1.4.

**Figure 2** Pace pulse without a QRS

The speed has been altered to show the pace pulse overshoot or tail. This 1 mV pace pulse shows an overshoot that does not return to the baseline for 60 ms or 0.06 seconds.
There are two stages in pace pulse processing:

- **Pace pulse detection** – For accurate paced analysis, all pace pulses must be detected first. Detection of pace pulse occurs at the point of care device. This permits highly accurate pace pulse detection on the unfiltered ECG signal.
- **Pace pulse rejection** – Using the 500 samples/second data, all detected pace pulses (including the overshoot) are suppressed before the ECG waveforms are processed by the QRS detector. In this way, the accidental detection of the pace pulse and its overshoot as a QRS is minimized.

**Note:** The rejection of pace pulses is done only on the ECG leads (primary and/or secondary leads) that are used by the algorithm for arrhythmia analysis.

**Filtering**

Next, the ECG waveform(s) are processed by two digital filters: a detection filter and a classification filter. These filters are optimized individually to enhance the performance of QRS detection and classification.

**Detection filter**

The detection filter removes low frequency noise (baseline wander) and muscle artifact, and accentuates the QRS complexes. P-waves and T-waves are diminished. This filter makes it easier to accurately detect the QRS and helps avoid erroneously detecting tall T-waves or artifact as beats. Since it distorts the true shape of the QRS, the output from the detection filter is used only for beat detection.

A special filter is used for neonatal ECG processing. This filter improves detection sensitivity of narrow neonatal QRS complexes.

**Classification filter**

The classification filter also removes signal irregularities, but it preserves the important features of the QRS. Since this filter does not distort the complex, the resulting ECG output can be used for feature measurements and beat classification.

**Step 2: QRS detection**

The algorithm’s challenge in QRS detection is to first locate R-wave peaks that become candidate peaks and then to make sure that they are not actually noise, P- or T-wave peaks.

**ECG amplitude**

To comply with IEC 60601-2-27 Section 20112.110115 and ANSI/AAMI EC-13 Section 4.2.6 specification, the detection threshold for the QRS cannot be less than 150 microvolts (0.15 millivolts). This specification is aimed at preventing the detection of P-waves, atrial fibrillatory waves, atrial flutter waves, or baseline noise as QRS complex during completed heart block or asystole. ST/AR removes the gain adjustment before the signal is analyzed for detection and classification. Thus increasing or decreasing gain at the point of care device has no effect on the ECG size used for QRS detection. The algorithm will analyze the ECG signal as it would appear at a gain x1. Therefore, for optimal performance and to prevent false alarms such as pause or asystole, it is important that the lead(s) selected for monitoring have adequate amplitude. If possible, select lead(s) which are greater than 500 microvolts (0.5 millivolts). This can be confirmed by comparing the ECG signal to the one-millivolt reference bar on the display and recordings.

**Biphasic QRS complex**

The QRS complex should be either mostly above or below the baseline and it should not be biphasic. ST/AR detects the notched or biphasic QRS by measuring from peak to baseline. The minimum QRS detection threshold cannot be less than 150 microvolts (0.15 millivolts) or the minimum detection threshold set by the user.

**Combining multiple leads into a single signal**

With multi-lead analysis, after both ECG signals pass through the detection filter, they are combined into a single signal for QRS detection. The contribution from each ECG lead to the QRS detection signal is proportional to its measured quality based on the waveform amplitude, and the amount of muscle and baseline noise. The weighting factors are updated at least every 200 milliseconds to allow for quick adaptation to signal quality changes.

The QRS detection signal can dynamically adapt to the quality of the incoming ECG signal(s), thus the impact of noisy signals to QRS detection can be reduced.
Generating the QRS detection signal using two ECG signals

Locating candidate R-wave peaks

The QRS detector checks the QRS detection signal for the presence of the peak R-wave. Searching begins after an absolute refractory period from the previously identified QRS complex. This helps prevent a T-wave from being identified as an R-wave. The value used for the absolute refractory period is 184 milliseconds for adult patients. A smaller value, 160 milliseconds, is used for pediatric and neonatal patients.

A moving search region is established at the end of the refractory period. For each search region, a new threshold is established based on:

- Noise around the search region.
- Distance from the previously detected R-wave.
- Averaged R-wave height.

The largest peak within the search region is considered a candidate R-wave.

Minimum detection threshold

To prevent P-waves, atrial fibrillatory waves, atrial flutter waves, or noise from being detected as QRS complexes during complete heart block or asystole, the detection threshold will never go below the larger of 1/5 of the average R-wave height, 150 millivolts (0.15 millivolts), or the minimum detection threshold set by the user. Any peak smaller than this value is not detected.

Noise rejection

After a candidate peak is detected, it is checked against a noise threshold to make sure that it is not a noise artifact or a QRS complex surrounded by noise. If the ECG lead(s) are determined to be noisy, then a beat label A (see Step 4: Beat classification) is assigned to the candidate peak and no classification is performed. With multi-lead analysis, the noise check is performed on each lead independently. Only the lead that is identified as noisy will be excluded from subsequent analysis.

Peak rejection

Before accepting the peak as a potential R-wave, there are two further tests which are carried out on each lead independently.

Potential false identification of the P-wave

To prevent a P-wave that is associated with a QRS from being counted as a QRS, it is checked against what is known about the previously identified P-waves. If it is found to be similar, the peak is rejected. In addition, to prevent P-waves from being erroneously counted as QRS complexes during complete heart block, three consecutive candidate peaks are further tested to see if they are actually consecutive P-waves. These peaks are rejected if they are found to be P-waves.

Potential false identification of the T-wave

If a candidate peak is found close to the preceding beat, it is tested to see if it might be a late T-wave. After a series of height and timing tests, the peak may be determined to be a T-wave and rejected. If it is determined that the candidate peak is not a P-wave or a T-wave, it is identified as a QRS complex and saved.

P-wave detection

After a QRS complex is located, a search takes place on each lead independently in the area prior to the beat to determine if there is an associated P-wave. This area is 200 milliseconds wide (104 milliseconds for neonates) and ends 120 milliseconds (56 milliseconds for neonates) before the R-wave peak. To be considered a P-wave, it must be at least 1/32 of the R-wave height and the P-R interval must be close to the average P-R interval.

In other words, the candidate P-wave must represent average characteristics in its relationship to the QRS. P-wave detection is used to differentiate between a sinus rhythm (normal QRS complexes with associated P-waves) and a supraventricular (SV) rhythm (normal QRS complexes without associated P-waves).

P-wave detection for adult/pedi

Step 3: Feature measurement

After a beat is detected, it is measured in several ways to determine its features. These features represent beat characteristics which can be used to discriminate between different types of beats.

The features measured are: height, width, area, and timing (a series of R-R interval measurements). With multi-lead analysis, the height, width and area are measured for each lead independently.

Step 4: Beat classification

Once the signal quality is checked and verified, and the QRS is detected and measured, the beat is labeled. Labeling means that the algorithm assigns the beat one of the following labels:

N = Normal
S = Supraventricular premature
V = Ventricular ectopic
P = Paced
‘ = Pacer spike (If the patient is both atrial and ventricular paced, the system will show two ‘ marks above the waveform aligned with the atrial and ventricular pacing.)
“ = Biventricular pacer spike
? = Questionable
L = Learning
If the signal quality is not good, the algorithm assigns one of the following labels to the waveform:

I = Inoperative
A = Artifact

When the algorithm detects a long R-R interval which violates one of the R-R interval limits, it labels the waveform:
M = No beat detected

When in Cardiotach (Arrhythmia Off) mode, N, S, V, and P are replaced with:
B = Beat detected

Beat labeling involves three major concepts:
1. The use of template families to represent recurring morphologies.
2. The use of initial learning of the patient’s normal morphology and/or paced morphology if the patient is paced.
3. The use of template families to aid classification of QRS complexes.

Grouping into template families
To aid the algorithm in labeling a new beat, previously detected beats that have similar shapes are grouped into template families.

Each template family contains the following information:
• Template family classification: Normal, Ventricular, Paced, or Unclassified.
• Waveform template, generated by averaging all the beats that are considered similar enough to be included.
• The number of complexes having this shape.
• The length of time since this shape was last seen.
• Statistical information on the beats’ feature measurements.
• If the patient is paced, pace pulse information associated with the beats.

For each patient, up to 16 different active template families can be created for each individual lead. To keep the template family information current, they are dynamically created and replaced as the patient’s beat shapes change.

If the patient begins to display a new beat morphology, a new template family is created. Older template families from beats the patient is no longer experiencing are automatically deleted.

Figure 8 Example of template families

Template matching
When a beat is detected, it is matched against the stored waveform templates for that patient. Matching means comparing the beat shape with a waveform template. This process involves overlaying the beat on the template and using a mathematical procedure to measure the differences between the two shapes.

Figure 9 Template matching

Learning
When arrhythmia monitoring starts, a learning process is initiated. The goal is to learn the patient’s normal complexes and/or the paced complexes if the patient with a pacemaker is in a paced rhythm. The learning process involves the first 15 valid (non-noisy) beats encountered during the learning phase.

The family selected to represent the beat labeled as normal includes the most frequently seen, narrowest and on-time beat. For this reason, learning should be initiated during periods when the patient’s rhythm is predominantly normal and the ECG signal is relatively noise free.

The algorithm automatically relearns the ECG waveform(s) whenever:
• ECG monitoring is started (including power on, restart or ECG On/Off).
Exiting Cardiotach (Arrhythmia Off) mode.

Paced mode is changed.

Patient category is changed. A profile change will cause a relearn if the patient category is different from the previous profile.

Exiting standby.

ECG source is changed.

Entering or exiting Demo mode.

A Leads Off inoperative condition lasts > than 60 seconds.

ECG mode is switched in or out of EASI mode.

When multi-lead analysis is active, the algorithm learns both the Primary and Secondary ECG leads simultaneously when the above conditions occur and the Learning ECG message is displayed. For minimum interruption of continuous monitoring, the ST/AR algorithm provides the flexibility for learning each lead independent of another lead. The algorithm continues monitoring one ECG lead while the other lead is being learned. The unaffected lead will be analyzed continuously without interruption.

When single-lead analysis is active, the algorithm learns the Primary ECG lead and displays the learning message during the above conditions as well, but will also automatically relearn when the Primary ECG lead or lead label is changed.

During a learning phase:

- Alarm timeout periods are cleared.
- Stored arrhythmia templates are cleared.
- Asystole, Vfib, and HR alarms (when there are enough beats to calculate the HR) are active. No other alarms are active.

If the learning phase takes place during a ventricular rhythm, the ectopic beats can be incorrectly learned as the normal QRS complex. This can result in the missed detection of events. Ensure that the arrhythmia algorithm is labeling beats correctly.

Beat labeling rules

Every beat is analyzed using beat labeling rules. These rules determine a preliminary label for each beat N, S, V, P, and ?. To help avoid artifact being labeled V, a new beat shape may be labeled as ? when initially seen. The beat labeling rules use a combination of the following information:

- Feature measurements.
- Timing/rhythm.
- Template matching.
- Morphology similarity to neighboring beats.
- Pace pulses associated with the beat (if paced mode On).

The rules emulate the behavior a clinician uses when analyzing an ECG waveform. Although the same rules are used for both the adult and neonate monitoring modes, several thresholds are adjusted for monitoring neonatal patients to account for their higher heart rate and narrower QRS complexes.

Pace beat classification

First, the algorithm classifies detected pace pulses as atrial and/or ventricular. To accomplish this, a search window is established prior to the QRS complex. Then, as pace pulses are seen in the search window, their distances from the beat are tracked. The location of the pace pulses in the search window determines whether it is atrial, ventricular, biventricular, atrial/ventricular (AV), or atrial/biventricular (A/Biv) as indicated in Figure 10. Pace pulses that fall within the non-capture region may result in fusion and pseudofusion beats.

Figure 10 Pace pulse search window

For the algorithm to consider the new beat as paced, the pace pulse must fall at a consistent distance from the QRS complex and be similar to the pace pulse associated with a paced template (see Figure 11).

Figure 11 Dual chamber paced template with associated pace pulses

If the pace pulses fall at random distances, they are considered to have no effect on the labeling of the beat (see Figure 12).
Figure 12 Random pace pulse distances indicate no association to the following beat:

Template family classification rules

After the normal family is initially learned, each newly created family remains unclassified until enough similar beats, usually less than five, are seen to classify it accurately.

Template families are classified as:
- **N** = Normal
- **V** = Ventricular ectopic
- **P** = Paced

The labels given to the beats using the beat labeling rules are used to determine the family classification.

A normal template can include **N** and **S** beats. For a template to be classified as **V**, a majority of members must be labeled **V**. By the ninth beat, if the template is not classified as **V**, the template is classified **N**. A paced template is determined by statistical analysis of all the pace pulses detected within 600 milliseconds of the QRS complexes that are included in the template family. In order for the algorithm to consider the template paced, pace pulses must fall at a consistent distance from the QRS. Based on the number of consistent distances found and their values, the paced template is classified as atrial, ventricular, biventricular or AV paced.

The template family classifications are continuously checked against labels given to the individual beats using the beat labeling rules. If many discrepancies are found, the template family is reclassified. In this way, the algorithm has a mechanism to correct inaccuracies made during template classification.

Beat labeling rules use current information to analyze ectopic activity, while template matching provides long-term memory to the algorithm. By using this combination of beat features, timing, and template matching techniques, the algorithm flexibly manages a variety of conditions with a high degree of accuracy.

Step 5: Heart rate calculation

Two different averages are used by the arrhythmia algorithm to determine the heart rate:

Normally, the heart rate is calculated by averaging the most recent 12 R–R intervals. Beats **N**, **S**, **P**, and **V** are all included in the calculation. This average gives a stable estimate of the underlying heart rate even when the rhythm is irregular.

When the heart rate drops below 50 bpm (80 bpm for neonates), the number of R–R intervals used in the average is dropped to four to improve the response time for the computed heart rate to reach the correct value during bradycardia.

Note: For the supraventricular and ventricular tachycardia alarms which have a user-definable **S** or **V** run length limit, the heart rate is calculated based on the user-selected **S** or **V** run length up to 9 maximum (that is, up to 8 R–R intervals).

For instance, if the VT alarm is user-defined as 5 or more consecutive beats labeled **V** and heart rate greater than 100 bpm, then 4 R–R intervals will be used to compute the heart rate to see if the rate exceeds the limit of 100 bpm. Likewise, if the VT alarm is user-defined as 10 or more consecutive beats labeled **V** and a heart rate greater than 100 bpm, then 8 R–R intervals will be used as that is the maximum possible.

Step 6: Atrial fibrillation detection

Atrial Fibrillation (Afib) detection is available for the Adult patient category only. Afib analysis is performed using both the R–R intervals and the P-waves. The algorithm uses three features for Afib detection: R–R irregularity, PR interval variability, and P-wave variability.

The R–R interval analysis is performed when the interval beats are both classified as **N** or **S**. It updates for every valid R–R interval found. Every 15 seconds, an averaged beat is formed by using beats classified as **N** or **S** that match the dominant normal template. P-wave detection is performed on the averaged beat. PR interval variability is calculated as the PR interval deviation between the current measurement and the running average. The P-wave region variability is determined by matching the P-wave region of the current and previous 15-second averaged beats.

For Afib to be detected for the 15-second period the:
- Normal beat R–R intervals must be irregular
- PR interval deviation must be large
- P-wave region must not match well

An Afib detection occurs when the above criteria are met for four consecutive 15-second intervals. Afib cannot be detected if beats are labeled as **V** or **P**. Since most atrial flutters have regular R–R intervals, they cannot be detected by the Afib algorithm.

End of Afib

To detect the end of Afib, two consecutive 15-second intervals must fail to meet the criteria for Afib detection. If Asystole, V–Fib or V–Tach is detected, the end of Afib will be triggered after 15 seconds.

Step 7: Ventricular fibrillation detection

Working in parallel with beat detection and labeling, a separate detector continuously examines the incoming ECG signal(s) for ventricular fibrillation. If a flutter or sinusoidal wave pattern persists for more than four seconds in both ECG channels, the monitor alarms for ventricular fibrillation.

Step 8: Rhythm and alarm detection

The results from beat labeling, HR calculation, atrial fibrillation detection and ventricular fibrillation detection are used by the rhythm and alarm detector as it measures the heart rate, determines the patient’s underlying rhythm, and identifies ectopic events.
The arrhythmia system's alarm structure

Alarm detection

The ST/AR arrhythmia monitoring algorithm is designed to analyze rhythm disturbances and irregularities which must pass a set of tests before the alarm is declared. Enhanced Alarm mode will declare up to 25 alarms. Basic Alarm mode will declare up to 10 alarms. Cardiotach (Arrhythmia Off) mode will declare up to 6 alarms.

Higher priority alarms, such as asystole, take precedence and supersede lower priority alarms, such as low heart rate. When a more serious alarm is detected, the lesser alarm message disappears and the higher priority alarm is activated. Consideration should be given to Alarm Chaining (see section "Alarm chaining") when reviewing alarm definitions.

The following two tables describe each alarm and the condition required to generate the alarm.

Table 2 *** Red Alarms

<table>
<thead>
<tr>
<th>Alarm</th>
<th>Condition required to generate alarm</th>
</tr>
</thead>
<tbody>
<tr>
<td>*** Asystole</td>
<td>No beat detected for a period &gt; the asystole threshold (2.5-4.0 seconds)</td>
</tr>
<tr>
<td>*** Ventricular Fib/Tach</td>
<td>Fibrillatory wave (sinusoidal wave between 2-10 Hz) for 4 consecutive seconds</td>
</tr>
<tr>
<td>*** Ventricular Tachycardia</td>
<td>A run of consecutive beats labeled as V with run length ≥ V-Tach Run limit AND ventricular HR &gt; V-Tach HR limit</td>
</tr>
<tr>
<td>*** Extreme Tachycardia</td>
<td>Heart Rate &gt; the Extreme Tachy limit</td>
</tr>
<tr>
<td>*** Extreme Bradycardia</td>
<td>Heart Rate &lt; the Extreme Brady limit</td>
</tr>
</tbody>
</table>

Table 3 * Yellow Alarms

<table>
<thead>
<tr>
<th>Alarm</th>
<th>Condition required to generate alarm</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Non-Sustained VT</td>
<td>A run of consecutive beats labeled as V with run length &lt; the V-Tach Run Limit AND ventricular HR &gt; V-Tach HR limit</td>
</tr>
<tr>
<td>* Ventricular Rhythm</td>
<td>A run of consecutive beats labeled as V with run length &gt; Vent rhythm run limit AND ventricular HR ≤ V-Tach HR limit</td>
</tr>
<tr>
<td>* Run PVCs</td>
<td>A run of &gt; 2 consecutive beats labeled as V with run length ≤ Vent rhythm run limit AND ventricular HR ≤ V-Tach HR limit</td>
</tr>
<tr>
<td>* Pair PVCs</td>
<td>Two consecutive beats labeled as V between 2 beats not labeled as V</td>
</tr>
<tr>
<td>* Pause</td>
<td>No beat detected for a period &gt; the pause alarm threshold1 (1.5-2.5 seconds)</td>
</tr>
</tbody>
</table>

**Alarm** | **Condition required to generate alarm** |
--- | --- |
* Missed Beat | No beat detected for a period > 1.75 times the average R-R interval for HR < 120 OR no beat detected for > 1 second with HR > 120 (Paced mode Off) |
* Pacer Not Capture | No beat detected for a period > 1.75 times the average R-R interval AND pace pulse(s) detected (Paced mode On) |
* Pacer Not Pace | No beat detected for a period > 1.75 times the average R-R interval AND no pace pulse(s) detected (Paced mode On) |
* SVT | A run of consecutive beats labeled as S with run length ≥ SVT run limit AND SVT HR > SVT HR limit |
* R-on-T PVC | For HR < 100, a beat labeled as V with R-R interval < 1/3 of the average R-R interval followed by a compensatory pause > 1.25 times the average R-R interval OR two such beats labeled as V without a compensatory pause occurring within 5 minutes of each other (Note: When HR > 100, 1/3 of the R-R interval is too short for detection) |
* Ventricular Bigeminy | A dominant rhythm of beats labeled as N, V, N, V, N |
* Ventricular Trigeminy | A dominant rhythm of beats labeled as N, N, V, N, N, N |
* PVCs > Limit | Within 1 minute, the number of beats labeled as V > the PVCs/min limit |
* Multiform PVCs | The occurrence of two differently shaped beats labeled as V within the last 60 beats AND each occurring at least twice within the last 300 beats |
*/** Heart Rate > Limit | Heart Rate > the high HR limit |
* Atrial Fibrillation | An irregular rhythm of beats labeled as N AND variability in PR intervals AND P-wave variability (for adult patient category only) |
* End of Atrial Fibrillation | Atrial Fibrillation no longer detected for the Afib end delay time (for adult patient category only) |
* Irregular HR | An irregular rhythm of beats labeled as N (R-R interval changes > 12.5%) |
* End of Irregular HR | Irregular HR rhythm no longer detected for the irregular HR end delay time |

1 When the setting for Pause and Asystole are both set at 2.5 sec., if an event occurs at > 2.5 sec., the Asystole alarm will be annunciated.

Note: ≥ is greater than or equal to a number, ≤ is less than or equal to a number.
Alarm activation and graded alarm structure

The ST/AR arrhythmia system’s alarm structure is based on priorities, with a system of *** Red, ** Yellow, * Yellow and INOP/technical alarms. Each type has a distinctive visual and audible alarm, enabling quick recognition of the severity of the alarm event.

Once an alarm is detected, it is immediately activated. An alarm message appears on the display and a distinctive audible alarm activates.

*** Red arrhythmia alarms
*** Red alarms, the most critical and life-threatening, always take priority over lesser arrhythmia alarms. They can never be individually turned off.

All *** Red, ** Yellow and * Yellow alarms will be turned off if:
- Alarms are suspended (Pause Alarms or Alarms Off selected).
- ECG alarms are Off (HR alarms Off) at the bedside monitor.
- All *** Red and * Yellow arrhythmia alarms are Off for telemetry.

Red alarm reminders
If Alarm Reminder is configured On for your device, you will get an audible reminder of alarm conditions that remain active after you have acknowledged the alarm. This reminder may take the form of a repetition of the alarm tone for a limited time, or an unlimited repetition of the alarm tone (this is the same as a new alarm). In Configuration Mode, you can set the interval between silencing the alarm and sounding the reminder tone to one, two, or three minutes.

* Yellow (short yellow) arrhythmia alarms
* Yellow arrhythmia alarms are considered lower in priority than red alarms, but still may indicate serious rhythm or rate disturbance. A * Yellow arrhythmia alarm can be superseded by a more serious * Yellow arrhythmia alarm event, or a red alarm.

* Yellow arrhythmia alarms have a distinctive sound and will sound for a short duration. The alarm message remains for up to three minutes as described below.

- If silenced:
  - And the condition ceases, the visual indicators will disappear.
  - And the condition continues, the visual alarm message continues. When the timeout period ends, an alarm is announced both audibly and visually. A new alarm is not stored.

- If not silenced:
  - And the condition ceases, the visual indicators will disappear after 3 minutes.
  - And the condition continues, the visual alarm indicators will continue. When the timeout period ends, an alarm is announced audibly. A new alarm is not stored.

* Yellow arrhythmia alarms are always set to latch visually for three minutes. End Afib Alarm and End Irregular HR alarm will latch visually for five minutes.

Individual * Yellow arrhythmia alarms can be disabled. Disabling * Yellow alarms for a particular patient does not affect any alarms on any other patient.

** Yellow (long yellow) HR limit alarms
HR alarms can be configured to be ** Yellow HR limit alarms. If configured to be a limit alarm, they will be announced as a continuous yellow level alarm. ** Yellow HR limit alarms will respond to the configured latching settings configured in your device.

Yellow alarm reminders
Similar to the *** Red arrhythmia alarms, if Alarm Reminder is configured On for your device and ** Yellow Heart Rate limit alarms are configured, you will get an audible reminder of alarm conditions that remain active after you have acknowledged the Heart Rate limit alarms. Alarm reminders, if configured On, will issue a reminder tone every 1, 2, or 3 minutes or, if set to realarm, a continuous alarm tone will sound.

* Yellow arrhythmia alarms have timeout periods. If you silence a * Yellow arrhythmia alarm and the alarm condition still exists, the visual indicators continue until the condition stops. You will get a realarming of the * Yellow arrhythmia alarm every time the configured timeout period has expired. If the timeout period is configured to 0, no reminder will be issued.

Atrial Fibrillation and Irregular HR alarms do not have timeout periods but do have reminders which can be configured.

INOP/technical alarms
INOP/technical alarms occur whenever the ECG signal cannot be properly analyzed due to noise or inoperative conditions. When active, the INOP/technical alarm continues, visually and/or audibly, as long as the condition exists, and stops automatically when the condition terminates. Since an INOP/technical alarm is a lower priority alarm, it will not override a red or yellow alarm should it occur during the same time a red or yellow alarm is occurring.

If 20 of the last 30 seconds are classified as either noisy or questionable (displayed by delayed beat annotations as predominantly A or ?), a Cannot Analyze ECG INOP/technical alarm is generated.

During this INOP/technical condition, the arrhythmia analysis continues and an alarm will be announced if an alarm condition is met.

Since the Cannot Analyze ECG INOP/technical alarm indicates that the effectiveness of the arrhythmia monitoring for the patient is compromised, a quick response to this alarm is important.

Alarm chaining
To prevent the confusion of redundant alarms or the activation of less important alarms while acknowledging serious alarms, the arrhythmia system sets alarm priorities through an alarm chaining system.

Related events, such as ventricular alarms, are grouped in a chain. The most critical alarms occupy the top of the chain and are followed by events in logical, descending order.

The manner in which the alarms are grouped and prioritized define how the alarms are announced. *** Red alarms having the highest priority are announced first if present. If there are no *** Red alarms detected, then the highest priority * Yellow alarm detected in any given alarm chain is announced. If alarms of the same priority in different alarm chains are detected, the alarm that occurred most recently is announced.
**Figure 13** Cardiotach (Arrhythmia Off) Mode alarm priority chain

**Figure 14** Basic arrhythmia alarm priority chain

Note: High/Low HR are always ** Yellow (Long) HR Alarms for Cardiotach Mode.
Enhanced arrhythmia alarm priority chain

Alarm behavior after annunciation

**Alarm timeouts**
- To reduce the number of unnecessary alarms, at the time when a * Yellow alarm is announced, a fixed non-extending timeout is initiated. The duration of the timeout period is user-configurable.
- Red alarms have no timeouts.
- During the timeout period, the alarm and all lower priority alarms within the same chain (group) will not be announced. Higher priority alarms or alarms from a different chain will be announced if detected during the timeout.
- The timeout period for first level (short inhibit) * Yellow alarms can be between 0 and 5 minutes. The timeout period for second level (long inhibit) * Yellow alarms can be between 0 and 15 minutes. Timeout periods will end once the configured amount of time has passed. They will also be cleared if any of the conditions that cause learning occur.

**Points to remember about alarms**
- Clinicians should acknowledge all alarms as quickly as possible.
- If an alarm condition exists, it is always activated unless it is turned Off, there is a higher priority alarm in effect, or the fixed timeout period is in effect.
- Yellow alarms can be user-disabled on devices.
- *** Red alarms never automatically reset with one exception. If your device is configured with Visual and Audible Latching Off, any Red alarm will cease once the condition ceases.
- All arrhythmia alarms are disabled if alarms are suspended or ECG alarms are Off (HR alarms Off) at the device.
Cardiotach (Arrhythmia Off) mode

The ST/AR algorithm also provides a Cardiotach (Arrhythmia Off) mode. The cardiotach algorithm can process one or two simultaneous ECG channels.

When Cardiotach (Arrhythmia Off) mode is utilized, the QRS detection is the same as when arrhythmia is turned On. This means that all the noise and rejection tests are performed.

From the beats detected, the heart rate is then calculated using the same formulas used in the arrhythmia algorithm. Working in parallel with beat detection, the asystole and ventricular fibrillation detection algorithms in arrhythmia analysis are used to detect the presence of asystole and ventricular fibrillation.

Note: High and Low HR alarms are always ** Yellow (Long Yellow) HR alarms when in cardiotech mode.

Steps to better arrhythmia monitoring

1. Optimize signal quality

   Good skin preparation is crucial to successful monitoring. A clean signal is integral to accurate arrhythmia monitoring. It is important to minimize or eliminate factors that create poor electrode contact, baseline wander, muscle artifact, or power line (50/60 Hz) interference.

   - Place electrodes on flat, non–muscular sites where the signal will not be impacted by either movement or bones.
   - Shave or clip hair from sites, if necessary, according to your hospital policy.
   - Clean each site thoroughly with soap and water, a non–alcohol wipe, or gauze. Do not use alcohol as it can dry out the skin.
   - Dry skin thoroughly.
   - Use ECG skin preparation paper (abrasive) or the skin preparation disk available on the electrode to remove dead skin cells and improve the conductivity of the electrode site.
   - Use quality electrodes.
     - All electrodes should be of the same brand and type to help minimize noise.
     - Electrodes that are packaged together in large quantities should be used shortly after the packaging is open or the packaging should be tightly resealed. Extended exposure to air will dry out electrodes prematurely and reduce their adhesive and conductive properties.
     - Check electrodes for moist gel. If you are not using pre-gelled electrodes, apply electrode gel to the electrodes before placement. Gel must be moist to provide a good signal.
     - Change electrodes every 24 hours. Increased baseline wander is the first indication that electrodes are dry and need to be changed.
     - For improved comfort, attach the lead wire to each electrode before applying the electrode to the patient.
     - Apply the electrode to the patient by pressing around the entire edge of the electrode. Placement of electrodes is important and may differ, depending on the patient cable and the monitoring lead placement selected.
     - Support cable and electrode wires. Artifact and baseline wander may increase if the skin under the electrode is stretched. Taping the wires may reduce this if your patient is active.

2. Select the appropriate paced mode

   Turn paced mode On if your patient has a pacemaker and turn paced mode Off if your patient does not have a pacemaker. It is important that the paced mode is set correctly for the patient you are monitoring. Having the wrong pacing mode will impact the effectiveness of the arrhythmia algorithm.

   - If the paced mode is Off for a patient with a pacemaker, the algorithm will not look for pace pulses. None of the paced beats will get classified correctly because the pace pulses are not detected and used in beat classification. While atrial paced beats may get labeled as N. Ventricular and AV paced beats may get labeled as V and generate false PVC alarms. More importantly, if the patient’s pacemaker fails to capture, the arrhythmia algorithm could mistake the pacer spikes as beats and continue generating a heart rate and not alarm for pacer not capture or asystole.
   - If the paced mode is On for a patient without a pacemaker, the algorithm’s effectiveness in detecting ventricular beats may be reduced because the algorithm cannot use the compensatory pause information following the beat labeled as V for non–paced ECG in classification. This may result in not receiving some PVC alarms.
   - If your device is set to Unconfirmed, ST/AR will utilize the algorithm for paced mode On.

3. Choose the best lead(s)

   - Choose a lead(s) where QRS amplitude is stable and has adequate amplitude (recommended amplitude greater than 500 microvolts (0.5 millivolts))
   - You may need to select a different lead or change electrodes if there is excessive noise, unstable or low R–wave amplitude, tall P–waves, tall atrial fibrillatory waves, tall atrial flutter waves, or tall T–waves.
   - If the system can do multi–lead analysis but only one lead has adequate stable voltage, change arrhythmia analysis to single–lead analysis or use the single lead QRS detection feature.

4. Ensure the best QRS complex

   Size and shape of the QRS are important for proper beat detection and classification. Use the following guidelines to choose leads which produce the best QRS morphology for analysis by the arrhythmia system. Check beat labels to ensure that the algorithm is labeling the beats correctly.

   The normal beat

   - R–wave is tall, not clipped or biphasic
   - T–wave is less than 1/3 the R–wave height.
   - If possible, QRS complex should be greater than 500 microvolts (0.5 millivolts).
   - P–wave, atrial fibrillatory waves, or atrial flutter waves are smaller than 1/5 the R–wave height, preferably less than 150 microvolts (0.15 millivolts) or the minimum detection threshold set by the user.

   The ectopic beat

   - Height is larger than 1/5 the average QRS height, 150 microvolts (0.15 millivolts), or the minimum detection threshold set by the user.
   - Beat should not be clipped.
5. Adjust minimum detection threshold

The QRS detection threshold is the level above which peaks will be counted as QRS complexes. The actual threshold at any time depends on the noise level present and the amplitude of the original ECG signal. The QRS detection threshold never goes below the larger of 1/5 the average R-wave height, 150 microvolts (0.15 millivolts), or the minimum detection threshold set by the user. Any peak smaller than this value is not detected.

False or missed alarms can occur if the QRS detection threshold is inappropriately set for the patient. To optimize the algorithm performance, adjust the minimum detection threshold to a level above the P-wave, atrial fibrillatory wave, atrial flutter wave, and/or noise to avoid these peaks from being counted as QRS complexes. The minimum QRS detection threshold may also need to be adjusted for ECG morphology changes.

6. Adjust alarms

Adjusting some alarms Off, changing the alarm criteria or adjusting the timeout periods will:

- Reduce the number of alarms.
- Alert the clinician to alarms specific to the patient.
- Reduce redundant alarms for known or chronic conditions.

Additional steps for monitoring patients with pacemakers

Careful observation during the arrhythmia system’s analysis of the paced patient is vitally important. Some pace pulses can be difficult to reject. When this happens, the pulses are counted as a QRS complex, and could result in an incorrect HR and failure to detect some arrhythmias or cardiac arrest. The clinician must always verify that paced pulse detection is indeed taking place.

First, paced mode must be turned On. The monitor relearns the patient’s rhythm using the paced patient algorithm.

While learning, the user should observe the delayed, annotated wave to be certain pace pulse tick marks are properly associated with pace pulses. Up to two pace pulse tick marks are displayed regardless of whether they are associated with the following beat. Thus for a dual-chamber pacemaker, there will be two separate marks (one for each pace pulse). A double tick mark will be displayed when biventricular pace pulses are detected by the system.

Consideration for ECG lead(s) selections:

- Paced complexes should be between 1 and 2 millivolts in size and taller than the pace pulse.
- Ventricular paced beats should be wider than the normal QRS complex.
- Pace pulses should not have visible repolarization (overshoot/undershoot). Repolarization causes increased width to the pace pulse and could result in the pace pulse being detected as a beat during pacing not capturing.

Figure 16: Avoid pace pulse repolarization tails
- Avoid fusion and pseudofusion beats. Fusion beats happen when an intrinsically conducted beat and a paced triggered beat occur simultaneously. Depending on the relative timing between the intrinsic beat and the paced beat, the QRS morphology can vary widely. Pseudofusion beats happen when an ineffective pace pulse occurs near or in a QRS. Usually there is no major distortion of the QRS morphology unless the intrinsic QRS is very narrow.

Figure 17: Illustration of fusion and pseudofusion beats
- Choose a lead where the ventricular pace pulse has the same polarity (that is, points in the same direction) as the QRS complex.
- Choose a lead with a normal QRS complex which is large but not too narrow.
- If ventricularly paced, change the ventricular paced rate to above the patient’s intrinsic rate if appropriate.
- For AV pacing, change the AV delay of the pacemaker to avoid pseudofusions if appropriate.

Special concerns for computerized arrhythmia monitoring

It is impossible to design a computerized arrhythmia algorithm that accurately analyzes 100% of all patients. In the following sections, several conditions that can cause difficulty for the algorithm are described.

Tall P- and T-waves

The algorithm is designed to selectively recognize and filter P- and T-waves to prevent classification as beats. If a T-wave is taller than the R-wave’s height or extremely delayed, correct classification is difficult. The T-wave might be detected and incorrectly labeled V, thus resulting in a R-on-T PVC or High Heart Rate alarm to be activated.
Tall P-waves, atrial fibrillatory waves, or atrial flutter waves may also be detected and incorrectly classified. For example, during complete heart block or pacemaker failure to pace or capture, tall P-waves, atrial fibrillatory waves, or atrial flutter waves (greater than 1/5 of the average R-wave height) may be erroneously counted, resulting in missed detection of cardiac arrest.

In most instances, tall T- and P-waves can be addressed by selecting different leads. However, in conditions such as extreme atrial hypertrophy, hyperkalemia, or decreased ventricular voltage, the P- and T-waves may be as tall as the R-wave despite careful lead selection.

Aberrant conducted beats

Since P-waves are not analyzed, it is difficult and sometimes impossible for the monitoring system to distinguish between an aberrant conducted supraventricular beat and a ventricular beat. If the aberrant beat resembles a ventricular morphology, it is classified as ventricular.

Select a lead where the aberrant conducted beats have an R-wave that is as narrow as possible to minimize incorrect calls. Ventricular beats should look different from these normal beats. Instead of trying to select two leads with a narrow R-wave, it may be easier to just select one lead and use single lead arrhythmia monitoring.

Atrial dysrhythmias

In some cases of atrial arrhythmias, the erratic atrial fibrillatory and flutter waves may be greater than the user-selected detection threshold. To avoid erroneous detection and false alarms, adjust the minimum detection threshold to be above the fibrillatory waves. This is another condition where single-lead arrhythmia monitoring option should be considered if it is difficult to select two leads that have low-level erratic baseline. In this condition where single-lead arrhythmia monitoring option should be considered if it is difficult to select two leads that have low-level erratic baseline.

Sinus arrhythmia

In some cases, during sinus arrhythmia, a false atrial fibrillation alarm can occur if the P-wave cannot be detected reliably or the P-wave morphology is varying.

Intermittent bundle branch block

The phenomenon of bundle branch or any of the other fascicular blocks creates a challenge for the arrhythmia algorithm. If the QRS during the block changes considerably from the learned normal, the blocked beat may be incorrectly labeled as V causing false PVC alarms.

Paced rhythms with pseudofusion beats

Avoid pseudofusion beats where the pace pulse falls near or inside the QRS complex. Pseudofusion beats may cause a narrow QRS complex to be removed as part of the pace pulse and overshoot removal process and result in false pause and/or asystole alarms.

Manual relearn

A manual relearn should be initiated if beat detection is not occurring or if beat classification is incorrect resulting in a false alarm. Remember, if the same signal condition exists which caused the algorithm to perform poorly, relearning will not correct the problem. The problem can only be corrected by selecting a different lead.

ECG statistics

The ST/AR arrhythmia algorithm computes ECG statistics from the ECG waves for sampling intervals of approximately one minute in length. Each statistical value describes the ectopic activity that occurred in the one-minute period of time leading up to its computation. Data is available in Basic or Enhanced Mode, even if the alarms are Off. No data is available in Cardiotach mode.
The following table describes the ECG statistics that are available and viewable from IntelliVue Information Center iX. A complete set of statistical data is available when the trend interval is set to Algorithm Interval. When the trend interval is set greater than one minute, only a subset of the statistical data will be available. If statistical data cannot be accurately computed for the interval of time, no data will be displayed.

**Note:** For statistics marked with an asterisk (*), data is only available if the trend interval is set to Algorithm Interval or 1 minute, otherwise no data can be displayed.

<table>
<thead>
<tr>
<th>Item</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percent of data available</strong></td>
<td>Percentage of data available for viewing in the selected time period</td>
</tr>
<tr>
<td><strong>Heart rate data</strong></td>
<td></td>
</tr>
<tr>
<td>Total beats</td>
<td>Total number of beats labeled N, S, V, P</td>
</tr>
<tr>
<td>Normal beats</td>
<td>Total number of beats labeled N</td>
</tr>
<tr>
<td>Percent poor signal*</td>
<td>Percent poor signal identified as sum of all R-R intervals with at least one beat labeled as A or ?</td>
</tr>
<tr>
<td><strong>Heart rate variability</strong></td>
<td></td>
</tr>
<tr>
<td>Percent irregular HR*</td>
<td>Percent of the sum of all R-R intervals with adjacent intervals which vary more than 12.5% and the beats are labeled as N or S and excluding M</td>
</tr>
<tr>
<td>Square root of NN variance*</td>
<td>Standard deviation of NN R-R intervals where R-R intervals are less than four seconds averaged</td>
</tr>
<tr>
<td>pNN50*</td>
<td>Percent of NNN beat sequences with changes of adjacent R-R intervals &gt; 50 ms</td>
</tr>
<tr>
<td>Pause events</td>
<td>Total number of asystole, pause or missed beats events</td>
</tr>
<tr>
<td><strong>Supra-ventricular ectopy</strong></td>
<td></td>
</tr>
<tr>
<td>Supra-ventricular beats</td>
<td>Total number of beats labeled S and N</td>
</tr>
<tr>
<td>Supra-ventricular premature beats</td>
<td>Total number of beats labeled S</td>
</tr>
<tr>
<td>Number of SVPB runs</td>
<td>Total number of runs consisting of three or more beats labeled S</td>
</tr>
<tr>
<td>Maximum HR in SVPB run</td>
<td>Maximum heart rate of runs with beats labeled S</td>
</tr>
<tr>
<td>Minimum HR in SVPB run</td>
<td>Minimum heart rate of runs with beats labeled S</td>
</tr>
<tr>
<td><strong>Ventricular ectopy</strong></td>
<td></td>
</tr>
<tr>
<td>PVC beats</td>
<td>Total number of beats labeled V</td>
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<tr>
<td><strong>Paced beats</strong></td>
<td></td>
</tr>
<tr>
<td>Atrial paced beats</td>
<td>Total number of beats labeled P with detected pace pulse &gt; 150 ms (&gt; 104 ms for neonate) before the QRS complex</td>
</tr>
<tr>
<td>Ventricular paced beats</td>
<td>Total number of beats labeled P with detection pace pulse ≤ 150 ms (104 ms for neonate) before the QRS complex</td>
</tr>
<tr>
<td>Dual paced beats</td>
<td>Total number of beats labeled P with two pace pulses, one detected ≤ 150 ms (104 ms for neonate) and one detected &gt; 150 ms (104 ms for neonate) before the QRS complex</td>
</tr>
<tr>
<td>Total paced beats</td>
<td>Total number of beats labeled P</td>
</tr>
<tr>
<td><strong>Percent of beats that were paced</strong></td>
<td>Percent of beats labeled P</td>
</tr>
<tr>
<td><strong>Percent of beats that were atrially paced</strong></td>
<td>Percent of beats labeled P with pace pulse &gt; 150 ms (104 ms for neonate) before the QRS complex</td>
</tr>
<tr>
<td><strong>Percent of beats that were ventricularly paced</strong></td>
<td>Percent of beats labeled P with a pace pulse ≤ 150 ms (104 ms for neonates) before the QRS complex</td>
</tr>
<tr>
<td>Item</td>
<td>Definition</td>
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<tr>
<td>Percent paced beats that were dual paced</td>
<td>Percent of beats labeled P with two pace pulses, one detected ≤ 150 ms (104 ms for neonate) and one detected &gt; 150 ms (104 ms for neonate) before the QRS complex</td>
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<tr>
<td>Number of paced runs</td>
<td>Total number of runs consisting of three or more beats labeled P</td>
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<td>Maximum HR in paced runs</td>
<td>Maximum heart rate of runs with beats labeled P</td>
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<tr>
<td>Minimum HR in paced runs</td>
<td>Minimum heart rate of runs with beats labeled P</td>
</tr>
<tr>
<td>Number of Pacer Not Pacing events</td>
<td>Total number of Pacer Not Pacing events</td>
</tr>
<tr>
<td>Number of Pacer Not Capture events</td>
<td>Total number of Pacer Not Capture events</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>Contains the total for the selected view duration</td>
</tr>
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</table>

**Conclusion**

An arrhythmia monitoring system is designed for continuous monitoring and is a tool to assist the clinician in managing and evaluating their patients. It is not designed to be a replacement for human surveillance and sound clinical judgment. Remember, correct operation of monitoring equipment along with close personal surveillance is the most reliable method of patient monitoring.