PHILIPS

IntelliVue

Patient Monitors

FAST SpO_2 Algorithm

Application Note

About this document

This application note describes the principles of Pulse Oximetry technology in general, and the Philips FAST SpO_2 algorithm used in Philips patient monitors. It deals with:

- common limitations and considerations relating to pulse oximetry
- the SpO_2 components, such as the pleth wave or signal quality indicator, that are displayed on the IntelliVue patient monitor
- the different alarm settings available for SpO_2 measurements on IntelliVue patient monitors
- the possibilities how to represent the measured SpO_2 result in different trend views
- how SpO_2 can be used as clinical decision support in neonatal surveillance

The patient monitor and the SpO_2 sensors Instructions for Use (IFU) contain important safety information. You must be familiar with the information provided in the IfUs before using the SpO_2 measurement. This document is not intended as a replacement for the related IFUs.

Principles of pulse oximetry technology

Pulse oximetry is a noninvasive method of measuring arterial oxygenation saturation (SaO_2) using light transmitted through tissue. The measurement principle of pulse oximetry is based on the differing red and infrared light absorption characteristics of oxygenated and deoxygenated hemoglobin.

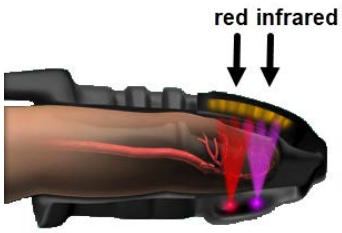


Figure 1: Red and infrared light

Oxygenated hemoglobin absorbs more infrared light and allows more red light to pass through. Deoxygenated (or reduced) hemoglobin absorbs more red light and allows more infrared light to pass through. Red light is in the 600-700 nm wavelength light band. Infrared is in the 850-1000 nm wavelength light band.

The following figure displays how oxygenated (HbO_2) and deoxygenated hemoglobin (Hb) absorb red and infrared light of a particular wavelength.

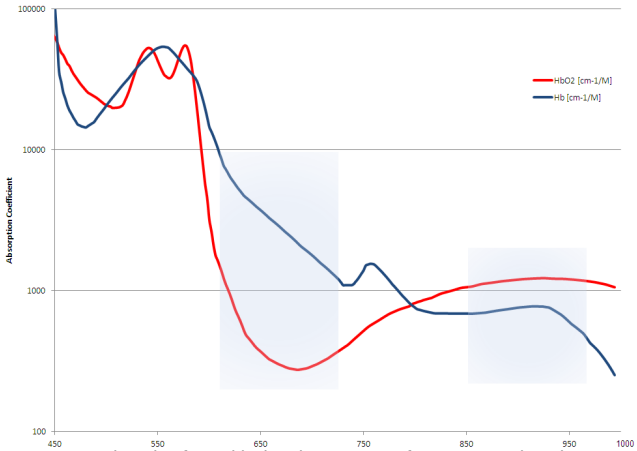


Figure 2: Red and infrared light absorption of oxygenated and deoxygenated hemoglobin, using data from W.B. Gratzer, Med. Res. Council Labs, Holly Hill, London, N. Kollias, Wellman Laboratories, Harvard Medical School, Boston

Arterial oxygenation saturation

The arterial oxygen saturation value represents the functional saturation, which is the percentage saturation given by the oxyhemoglobin (HbO_2) concentration divided by the sum of the oxyhemoglobin (HbO_2) and the deoxyhemoglobin (Hb) concentrations.

$$SpO_2 = \frac{HbO_2}{HbO_2 + Hb} \times 100\%$$

Figure 3: Definition of functional saturation

Absorption at the measurement site

Opposite the light source, a photo detector receives the light that passes through the measurement site. The light emitted at the measurement site is absorbed by arterial and venous blood, as well as by tissue and bones. The received signal consists of the pulsatile portion (AC) caused by the pulsating arterial blood flow, and the non-pulsatile portion (DC). Only the pulsatile portion of the signal is of interest as it represents the pulsing of the blood in the arteries and each individual pulse can be seen. The pulsatile portion of the signal makes up the characteristic pleth wave.

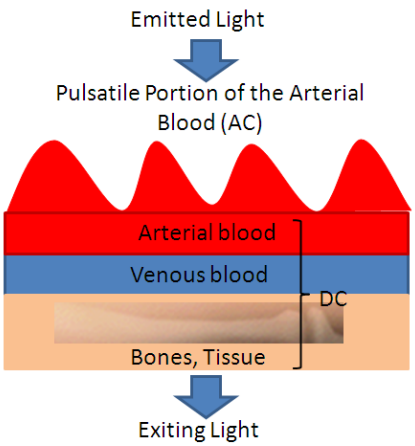


Figure 4: Absorption at the measurement site

The traditional algorithm examines how the signal coming from the sensor changes over time due to arterial blood pulsation. The algorithm tries to find the minimum and maximum of the red and infrared signals that correspond to the pulsation. From the ratio of minimum and maximum values of both red and infrared signals, the algorithm calculates a saturation value.

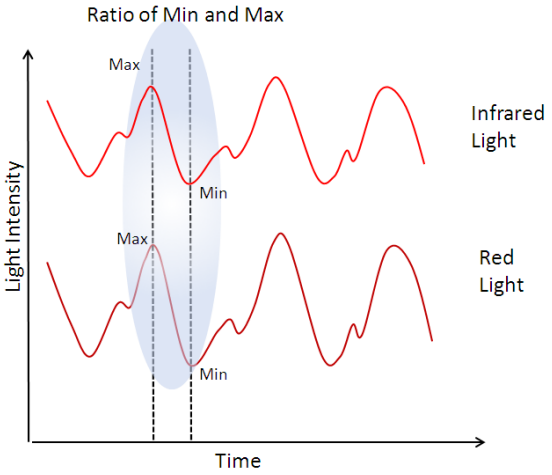


Figure 5: Determining minimum and maximum values for saturation calculation

Any "noise" (artifacts) overlaying the red and infrared signals can affect the correct detection of these minimum and maximum values. Artifacts can therefore cause inaccurate SpO_2 measurement results. A traditional algorithm assumes that, by averaging over time, most noise should be eliminated.

Problems with this approach are:

- Significant noise (for example due to patient motion) that occurs simultaneously with a minimum or maximum of the pulse is included in the calculation.
- Difficulty to detect the correct pulse if the noise is also "pulsing" (as it is the case, for example, with shivering).
- If the pulses are weak (as it is the case with low perfusion), the signal is more or less permanently disturbed by any noise present in the environment. This means the ratio between the infrared and red absorption is difficult to calculate accurately.

Philips FAST SpO_2 technology

The Philips FAST (Fourier Artifact Suppression Technology) SpO_2 algorithm derives SpO_2 using the absorptions of red and infrared light. But unlike the traditional algorithm described previously, the Philips patented FAST algorithm takes an entirely different approach to identify the physiological signal reliably.

Instead of examining how the strength of the photo-plethysmographic signals changes over time, the FAST SpO_2 algorithm examines the strength of the different frequency components that make up the signals. The most significant frequency component of the physiological signal is the pulse rate. Due to the characteristics of a heart beat and the way the blood pulses in the arteries, there are also multiples of the pulse rate, so called harmonics.

The following figures and tables use examples that explain how the FAST SpO_2 algorithm works with an ideal pleth wave, and a distorted pleth wave by motion artifact.

Overview of the FAST SpO_2 algorithm with an ideal pleth wave

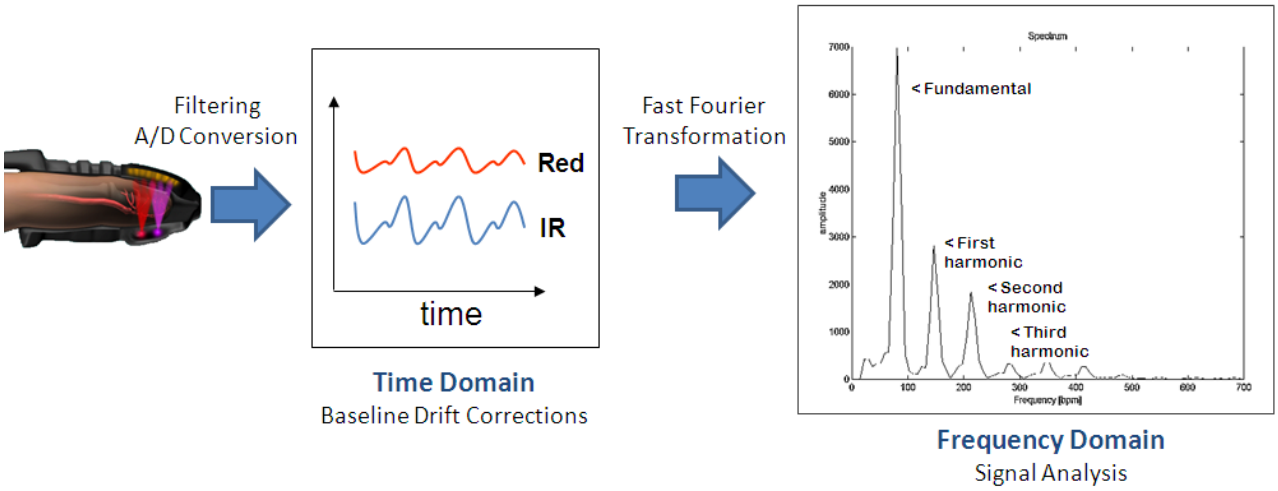
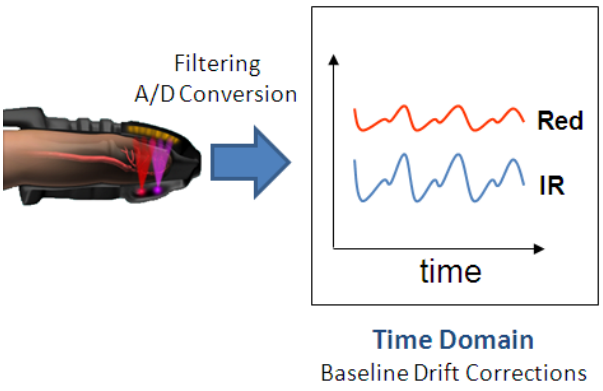


Figure 6: Fast Fourier transformation with an ideal pleth wave without artifacts

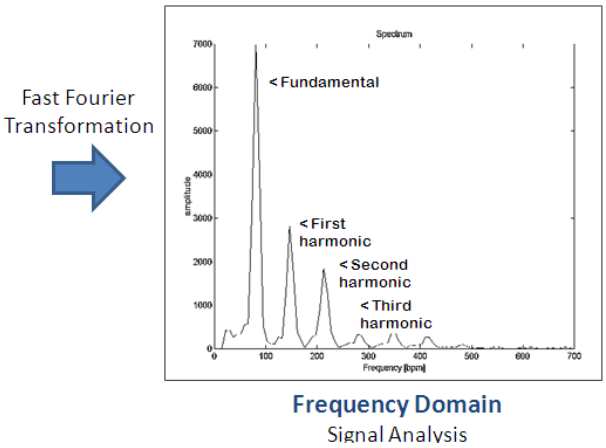
Details

After converting the signal from analog to digital (A/D - conversion), the red and infrared signals are in a so called "time domain". The time domain graph shows how the signal changes over time.
The algorithm starts with baseline drift corrections of the red and infrared signals.
But, unlike traditional pulse oximetry, Philips' patented FAST SpO_2 algorithm applies FAST Fourier transformation to break down the red and infrared signals into individual frequencies.

Algorithm



The Fast Fourier transformation allows the use of sophisticated analysis in the frequency domain to distinguish the physiological signal from the "noise", or artifact.
Accordingly, an ideal pleth wave consists of a fundamental frequency, which is the pulse rate, and a very characteristic set of harmonic frequencies. The so-called "harmonics" can be found along the multiples of that fundamental frequency.
The number of harmonics and their amplitudes make the pattern unique.



Details

In this waterfall diagram, the frequencies are displayed over a period of time to illustrate the fundamental frequency and their harmonics.
Here you can easily identify the fundamental frequency (as it corresponds to the pulse) and their harmonics (relatives to the pulse).
In this example, the fundamental frequency is about 60 bpm, the first harmonic is found at about 120 bpm, and the second harmonic at about 180 bpm.

Algorithm

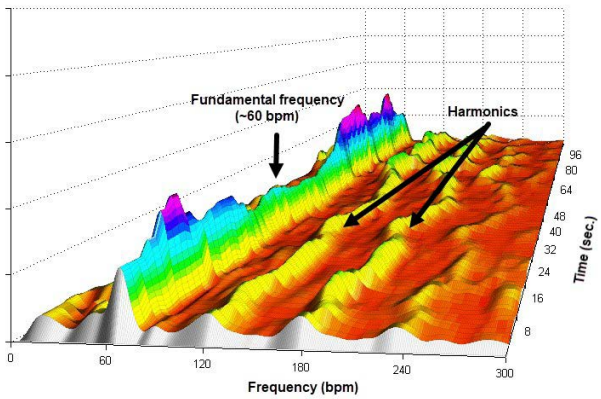


Table 1: FAST SpO_2 algorithm

Overview of the FAST SpO_2 algorithm with a pleth wave distorted by motion artifact

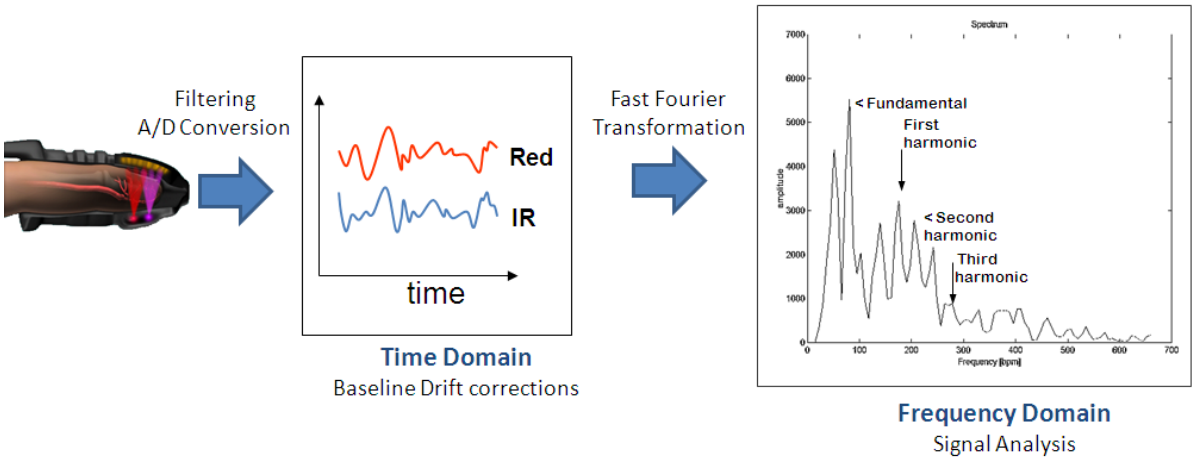
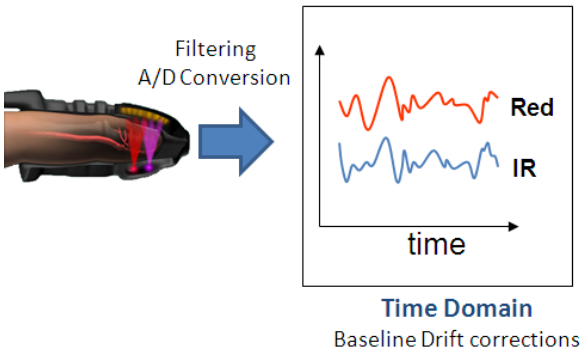


Figure 7: Fast Fourier transformation with a pleth wave with artifacts

Details

This example displays the photo-plethysmographic (pleth) waveform which is significantly distorted by motion artifact.
The time domain graph shows how the signal changes over time.
The algorithm starts again with baseline drift corrections of the red and infrared signals.

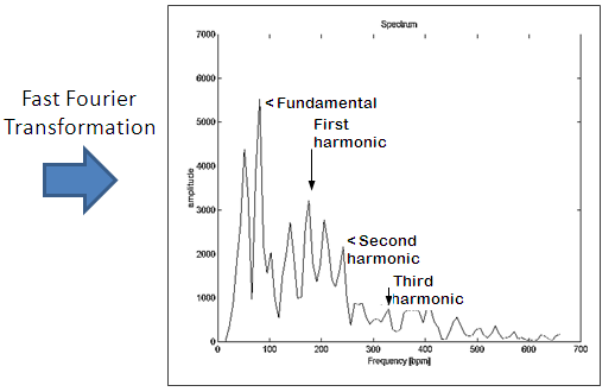
Algorithm



Details

The frequency spectrum contains not only the characteristic components of the ideal pleth wave, but also many other overlaying frequencies of varying amplitudes. The purpose of the algorithm is to pick out the physiological components and distinguish them from the rest.
Artifacts, from patient movement for example, generally do not have the same frequency characteristics as a physiological signal. Any wave, no matter what shape, consists of many individual frequencies that make up the waveform's characteristic spectrum.

Algorithm



Frequency Domain
Signal Analysis

In the waterfall diagram, the fundamental frequency is represented by the peak with a consistent frequency and amplitude over time, in contrast to the inconsistent artifact components.
At least one of the harmonics of that fundamental frequency is also easily identified in this picture.
Once found, the pulse frequency is verified by looking for harmonics. In this example, the pulse is determined to be about 60 bpm. There is also a detectable signal at about 120 bpm, which is the first harmonic.

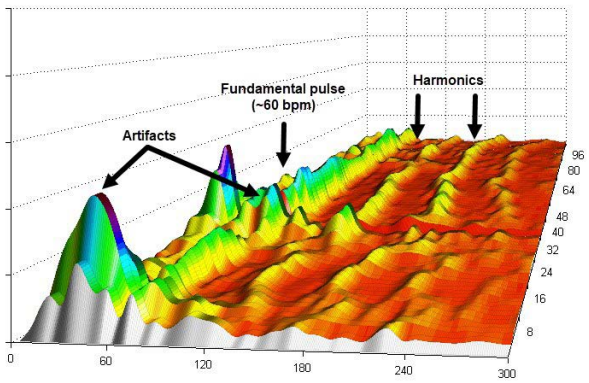


Table 2: FAST SpO_2 algorithm

The core of the FAST SpO_2 algorithm is a Philips developed scoring technique. The correct peak in the Fourier spectrum is found by assigning scores to all peaks in the spectrum, and then using total scores to distinguish the clinically relevant signal from the noise and artifact. This method is patented by Philips.

This approach not only increases measurement accuracy but also significantly reduces the number of false alarms, an achievement that has been proven in laboratory and clinical studies.

The ability to reject artifacts this way, is particularly important for making measurements in situations with low perfusion and/or patient movement.

Considerations and limitations relating to pulse oximetry

Pulse oximetry is an accurate and safe method for the measurement of oxygen delivered to the tissue. Several factors should be considered when using it, since these variables alter the accuracy of the readings.

Conditions that impact pulse oximetry readings

Effects of non-functional hemoglobin on oxygen saturation measurements

In order to judge a patient's condition, blood oxygen saturation is expressed as the percentage of the total functional hemoglobin that is saturated with oxygen. If there is a large amount of non-functional hemoglobin such as met hemoglobin (METHb) or carboxyhemoglobin (HbCO), the reading will not be accurate, because non-functional hemoglobin also absorbs infrared and red light [1, 2, 4].

Dyes

Some surgical procedures, especially in cardiology and urology, call for the injection of dyes into the blood in order to trace blood flow. These dyes affect the light transmission through

the blood and can lead to incorrect readings. If the patient's blood contains any of the following dyes, you cannot use pulse oximetry to measure oxygenation [1, 2, 4]:

- Methylene blue
- Indiocyanine green
- Indiocarmine

Increased Bilirubin concentrations, a breakdown product from red blood cells, tend to overestimate the measured oxygen saturation [1].

Application error

The optical windows of emitter (LED) and receiver (photo diode) must be covered fully by the application site, for example the finger, ear lobe, or ala. Applying the SpO_2 sensor incorrectly will lead to inaccurate readings.

Nail polish

Some nail polish and artificial fingernails may cause false readings due to limited light transmission through the tissue [2, 3].

Humidity

When measuring SpO_2 with neonates that are lying in an incubator, the humid atmosphere inside can cause inaccurate measurements when the adapter cable connected to the sensor is located inside the incubator. Therefore, Philips recommends placing the adapter cable outside the incubator.

Light interference

High level of ambient light (including IR warmers), strobe lights, or flashing lights (such as fire alarm lamps) can cause inaccurate SpO_2 readings [1, 2, 3, 4].

Excessive patient movement and vibrations

External interference may be caused by rhythmic patient movement, for example shivering [1, 2, 3, 4].

Skin pigmentation

A patient's skin pigmentation can affect some pulse oximeters' ability to accurately measure oxygen saturation [10, 11, 12].

Limitations on pulse oximetry readings

In some situations even a good saturation level does not ensure appropriate oxygen delivery to the tissue. For example:

Anemia

Bleeding or damage to red blood cells may cause anemia, a lack of red blood cells and thus hemoglobin in the blood to oxygenate the tissue. The small amount of functioning hemoglobin in the blood may be well saturated with oxygen, so the patient may have a normal SpO_2 reading, but the patient may not have enough oxygen going to the tissue [1, 2, 3, 4].

When SpO_2 is measured at one of the body's peripheral sites, for example a finger or toe, low perfusion at these measurement sites decreases the arterial pulsation. This may contribute to inaccurate readings. Studies, where low peripheral perfusion was simulated, have shown that low perfusion at a peripheral measurement site can lead to delayed decreasing SpO_2 readings during hypoxia [5].

Low perfusion

Low perfusion at the measurement site can be caused by [1, 2, 3, 4, 5]:

- Low cardiac output, for example during cardiopulmonary bypass surgery.
- Shock: The body reduces blood supply to the limbs and extremities as a response to injury, or even the fear of injury, to maintain the blood supply to vital organs even in the event of severe blood loss. Because of this reduced perfusion, pulse oximeters may give misleading readings on patients in severe shock.
- Hypothermia: The body reduces the heat lost by the skin by constricting the peripheral blood vessels. Cold is a common problem, often seen with car accident victims and patients undergoing brain or open heart surgery during which the patient's body temperature is lowered. Cold also causes shivering, which can lead to movement artifacts.
- Medication: Many kinds of medication, such as vasoactive drugs or nerve blockers, can lead to the constriction of peripheral blood vessels.

You may want to use oxygen saturation to judge oxygen partial pressure (PaO_2). SpO_2 is related to PaO_2 in a complex way, described by the Oxyhemoglobin Dissociation Curve. Many variables can affect hemoglobin's affinity for oxygen [4].

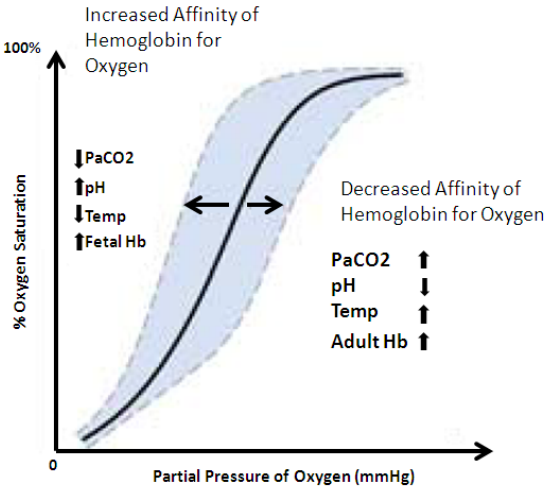


Figure 8: Oxyhemoglobin Dissociation Curve

This figure shows that, for example, an increased pH shifts the curve to the left. Fetal hemoglobin, which binds more readily with oxygen than adult hemoglobin, especially affects the curve. The relationship between SpO_2 and PaO_2 is not simple, so judging one measurement from the other should only be attempted with caution.

SpO_2 sensor

Applying the SpO_2 sensor

Different SpO_2 sensor types for different measurement sites need to be accurately applied to ensure proper SpO_2 readings. Therefore Philips recommends to follow the detailed instructions for applying the sensor described in the SpO_2 sensor IfU of each sensor. In general, when applying the sensor, the application site should match the sensor size.

Typical sensor sites

The following table explains the typical sensor sites:

Adult and pediatric	Infant	Neonate
Finger	Big toe	Foot

Adult and pediatric	Infant	Neonate
Lobe of the ear	Thumb	Palm of the hand
Ala		Big toe
		Thumb

Table 3: Typical sensor sites

SpO_2 sensor implications

When selecting a sensor site, priority should be given to an extremity free of an arterial catheter, blood pressure cuff, or intravascular infusion line. These conditions can increase the probability of an impaired measurement due to reduced arterial perfusion or venous congestion [3].

The preferred application site for newborns immediately after birth is the right hand. SpO_2 values on the right hand (pre-ductal) are more representative of brain oxygenation. For more information about SpO_2 in neonatal surveillance, see "SpO2 included in Clinical Decision Support tools in neonatal surveillance" on page 16.

For accurate SpO_2 readings, Philips recommends using only sensor sites with the corresponding SpO_2 sensor, specified in the IfU. The currently available SpO_2 sensors are designed to rely on a relatively homogenous vascular bed for accurate SpO_2 measurements. When applying the sensor to another application site, for example at the wrist, even if the signal seems to be good, there is a high risk that the measured SpO_2 value does not reflect the patient's actual saturation. The error in the SpO_2 value is not only that there could be an offset, but also SpO_2 changes are often not properly tracked and therefore, even with a strong desaturation, the reported SpO_2 value may continue to stay at higher levels. The reason for this is the specific vascular condition at the wrist. With the larger vessels at the wrist the pulsatile signal may be very strong, but it is more likely that the optical paths for the different wavelengths used in pulse oximetry are not aligned anymore, which causes erroneous SpO_2 readings.

Available SpO_2 sensors

For compatible SpO_2 sensors please refer to the patient monitor and SpO_2 sensor Instructions for Use.

Philips FAST SpO_2 on IntelliVue patient monitors

The displayed values (SpO_2 numeric, derived pulse rate and perfusion indicator value) are typically measured continuously, but depending on the configuration and for specific use cases they can also be displayed as timed or "spot check" values. IntelliVue patient monitors provide the following labels:

SpO_2 labels

SpO_2	SpO_2l (SpO_2 left)
SpO_2pr (neonatal pre ductal)	SpO_2r (SpO_2 right)
SpO_2po (neonatal post ductal)	SpO_2T (when sourced from telemetry)

Table 4: SpO_2 labels

Pulse rate from plethysmogram

Philips FAST SpO_2 provides a pulse rate derived from the pleth wave based on detected pulsations per minute. When sourced from telemetry the label **PulseT** is shown, in all other cases the label **Pulse** is shown. The displayed pulse rate numeric reflects arterial pulsation at the measurement site.

Plethysmogram presentation (pleth wave) - signal strength

Philips FAST SpO_2 produces a continuous photo-plethysmogram in real time as a visual indication of the patient's pulse and signal quality. The pleth wave channel provides outer and inner gridlines to support evaluation of the signal strength using the pleth wave size as an indicator. If the size of the pleth wave is smaller than the two inner gridlines, it is more likely that low perfusion INOPs occur.

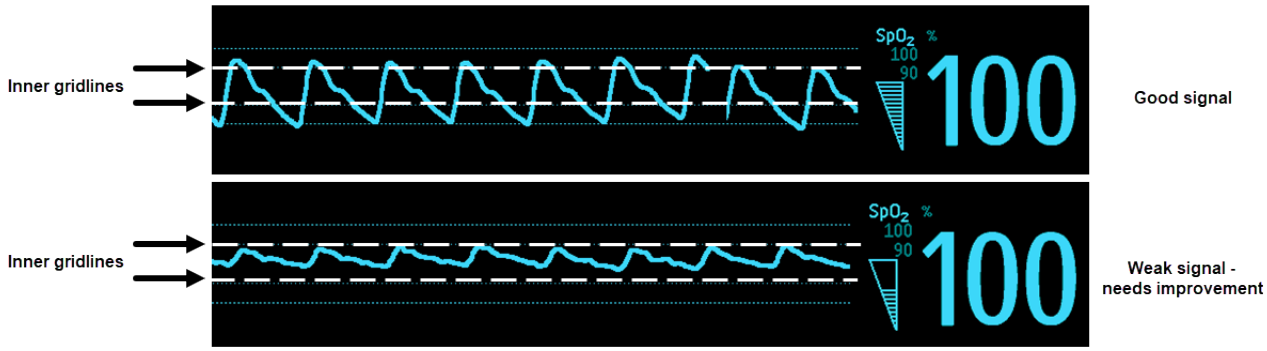


Figure 9: Pleth wave - signal strength

Signal quality indicator

The SpO_2 numeric is displayed together with a signal quality indicator which gives an indication of the reliability of the displayed values. You can use this indicator to assess the signal quality when you doubt a measured SpO_2 value.

The level to which the triangle is filled shows the quality of the signal. For example the indicator on the right shows a medium signal quality. The signal quality is at a maximum when the triangle is completely filled.

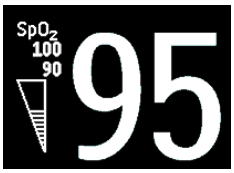


Figure 10: Signal Quality Indicator

Perfusion indicator value

The perfusion indicator value gives a value for the pulsatile portion of the measured signal (AC) caused by the pulsating arterial blood flow in relation to the non-pulsatile portion of this signal (DC)[1].

As pulse oximetry is based on the pulsatile nature of the signal, you can also use the perfusion indicator value as a quality indicator for the SpO_2 measurement.

Figure 11: Perfusion indicator value

The perfusion indicator value is helpful to determine the signal quality, and it is an indicator for the perfusion (change) at the measured location.

Although the perfusion indicator value is not a measure of perfusion, trends in the value can be used to interpret changes in perfusion conditions.

The larger the perfusion indicator value, the better the measurability of SpO_2. For values less than 1 and particularly for values less than 0.3, Philips recommends to reposition the sensor or find a more central site.

For neonatal patients the signal strength is weaker than for an adult. Typical values for the neonatal patients vary between 0.3 and 5.

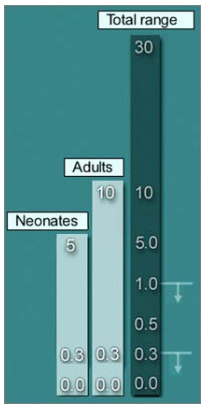


Figure 12: Range of the perfusion indicator value

Typical perfusion values for adults range from 0.3 to 10.

Typical perfusion values for neonates with weaker signal range from 0.3 to 5.

Perfusion change indicator

The perfusion change indicator is a graphical symbol which shows the change in the perfusion indicator value, relative to a reference value which can be set in the SpO_2 setup menu. When a reference value is set, the perfusion change indicator is displayed next to the perfusion indicator value.

It is a graphical representation of the perfusion change. Again, the perfusion indicator value is not a direct measure of the patient's perfusion. You can use the trend to determine whether the patient's perfusion is changing at the measurement site. This could trigger a closer examination of the sensor placement and the patient status, for example.

1. When using a heart-lung machine, the pulsatile portion of the signal can be nearly zero. Although the perfusion is good the perfusion value is small.

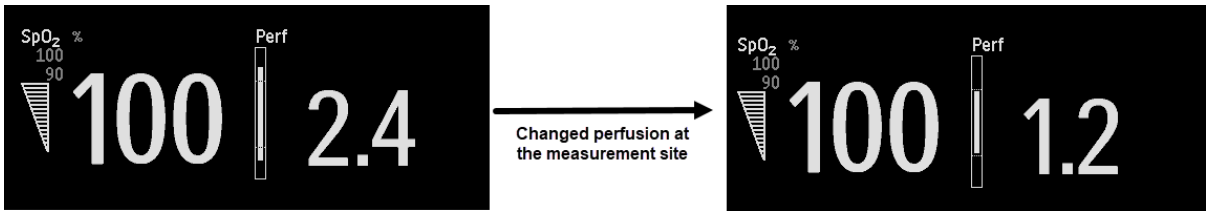


Figure 13: Example of changed perfusion at the measurement site

The trend of the perfusion indicator value can support health care professionals:

- when administering vasoactive drugs
- during anesthesia
- suggesting a significant delay between central saturation changes and the saturation changes at the measurement site, due to extreme low perfusion conditions.
- or whenever changes in perfusion could be critical.

Perfusion indicator value - Q&A

Why might the perfusion indicator value differ between fingers/sites of the same patient?

The perfusion indicator value depends on the specific sensor design, the geometry of the application site, as well as the optical characteristics of tissue and bone of the measurement site.

For example, stiffer arterial vessels might result in smaller changes in blood volume during systole relative to the overall arterial blood volume, so the ratio between AC/DC would differ across the body.

This may explain why perfusion differs between application sites of the same patient. Of course, perfusion may actually be different for different fingers. Such differences have been observed during controlled desaturation studies. Differences in vasculature between the fingers can also cause significantly different delays of saturation changes between different fingers on the same hand.

Another potential impact on the ratio between AC/DC for each wavelength is a change in saturation. Philips FAST SpO_2 uses a patented method to compensate for this effect to make the perfusion indicator value independent of actual saturation.

The perfusion indicator value is therefore not an absolute measure of perfusion, but a relative measure of perfusion at a given site.

Why does the perfusion indicator value go up when the patient raises a hand? (one would expect the perfusion to go down)

When you raise your hand above the heart level two things occur physiologically. First, the static blood pressure decreases, causing both the pulsatile arterial blood volume and the non-pulsatile venous blood volume to decrease. Next, because of the drop in static blood pressure, the tension on the vessel walls decreases and in turn causes the vessel diameter to shrink. As a result, the equivalent pulsatile blood flow will result in a larger relative extension of the vessel diameter. A puff into a half-inflated balloon has a bigger effect than the same puff into a fully inflated balloon, because the volume of one puff causes a larger delta in the diameter of the half-filled balloon. The "puff" might actually be smaller in the raised hand, but still causes a larger extension of the arteries.

Even if the overall pulsatile flow volume (related to the stroke volume of the heart) remains unchanged, then the pulsation portion increases.

The increase of the pulsation proportion in the absorption signals causes the perfusion indicator value to go up.

SpO_2 alarming

There is a delay between a change in the oxygen saturation at the measurement site and the corresponding audible alarm indication at the monitor. This delay has the following cumulative components:

- **Algorithmic processing time** (non-configurable): about 10 seconds
- **Averaging time** (configurable): 5, 10, or 20 seconds

  For more information on averaging time, see "Averaging time" on page 9.
- **Alarm delay time** (configurable): 0 to 30 seconds if standard alarm delay is used, or varying if Smart Alarm Delay is used.

  For more information on alarm delay times, see "SpO2 alarm delays" on page 9.
- **System alarm delay** (non-configurable): less than 4 seconds

  The system alarm delay is the processing time the system needs for any alarm to be indicated on the monitor, after the measurement has triggered the alarm.

When the SpO_2 value crosses an alarm limit, the delay period starts. During the delay period, there is **no alarm indication** that the limit has been crossed.

If the SpO_2 value returns inside the limits during the delay period, no alarm is issued. If the SpO_2 value is still outside the alarm limit at the end of the delay period, both audible and visual alarm indication starts after the system alarm delay.

Averaging time

Depending on your monitor configuration, you may be able to change the time over which the SpO_2 value, pulse rate and perfusion are averaged before displaying.

The longer the average time, the longer the time needed until any physiological event is reflected in the SpO_2 value displayed on the monitor.

A short averaging time is useful when few artifacts are expected, or when there is a high probability of significant physiological events requiring immediate responses. Use slow averaging where you expect the artifact content to be relatively high.

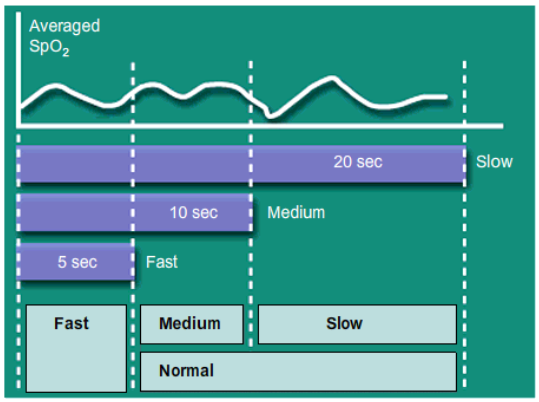


Figure 14: Averaging Time

SpO_2 alarm delays

For SpO_2 high and low limit alarms, there are two different types of alarm delay time. The standard alarm delay is set to a fixed value. The Smart Alarm Delay varies, based on an intelligent algorithm, and can be used instead of the standard alarm delay.

The Desat alarm always uses the standard alarm delay.

Standard alarm delay

The standard alarm delay time can be configured to a fixed value between 0 and 30.

Alarm delay time	Setting
SpO_2 high alarm delay time	0 to 30 seconds Default 10 seconds
SpO_2 low alarm delay time	0 to 30 seconds Default 10 seconds
Desat alarm delay time	0 to 30 seconds Default 20 seconds
Adjustment	1 second steps

Table 5: SpO_2 delay time

In the following figure you see the delay time in an example: if the SpO_2 value violates the low alarm limit for more than 10 seconds, the low alarm is indicated. If the SpO_2 value violates the low or Desat alarm limit only for a short time, for example 5 seconds, no alarm is indicated.

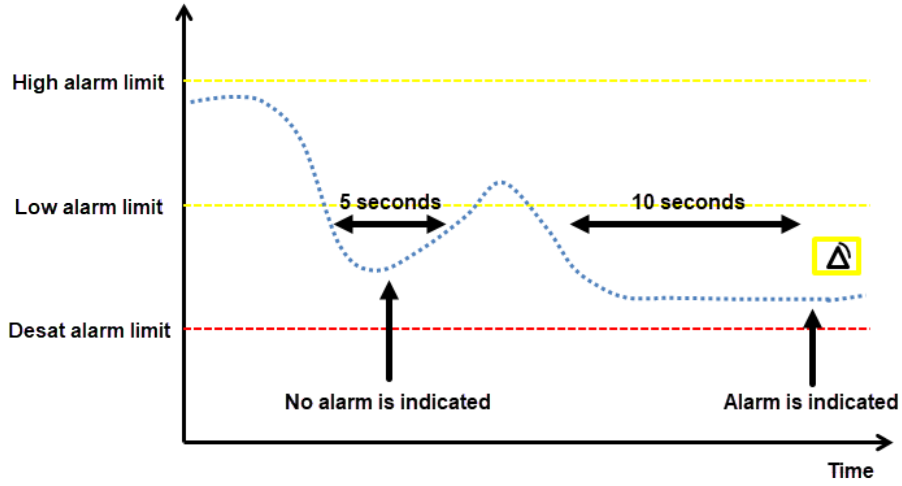


Figure 15: Standard alarm delay example

Smart Alarm Delays

The Smart Alarm Delay functionality is currently not available in China or in clinical environments under NMPA control.

When Smart Alarm Delays are used, the delay before the indication of an SpO_2 high or low limit alarm depends on the amount by which the limit is exceeded and for how long. This capability can be used to avoid alarms when the SpO_2 values show a pattern of recovering after a limit violation.

There are three modes available: Short, Medium and Long. All modes have a minimum delay of 10 seconds. The maximum delay at minimal limit violation is 25 seconds for **Short** mode, 50 seconds for **Medium** mode and 100 seconds for **Long** mode.

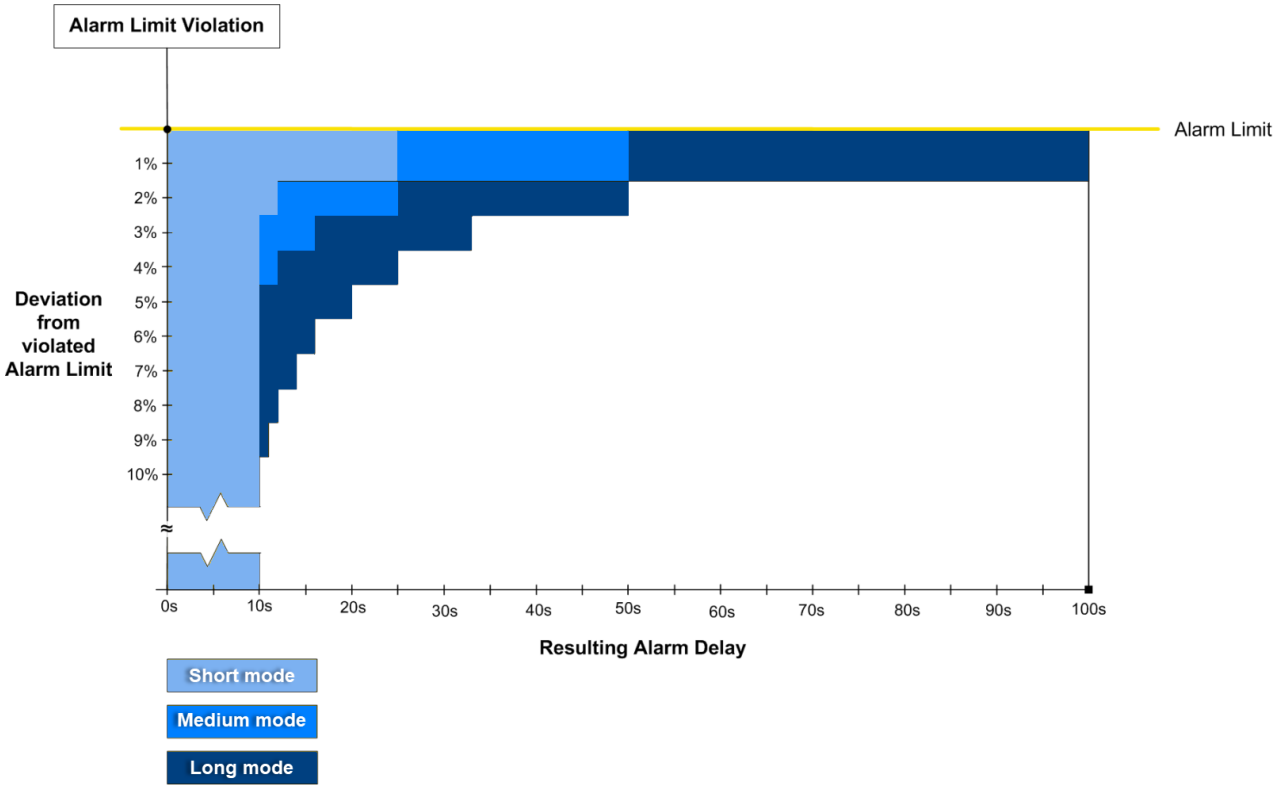


Figure 16: Smart Alarm Delay overview

This diagram shows the relationship between the alarm delay and the deviation from the alarm limit. The shaded areas on the diagram show the area in which SpO_2 values can violate the alarm limit without causing an alarm to be indicated. The area is smallest for the Short mode, and is extended for the Medium and Long modes by the corresponding areas shown above.

Example with Short mode

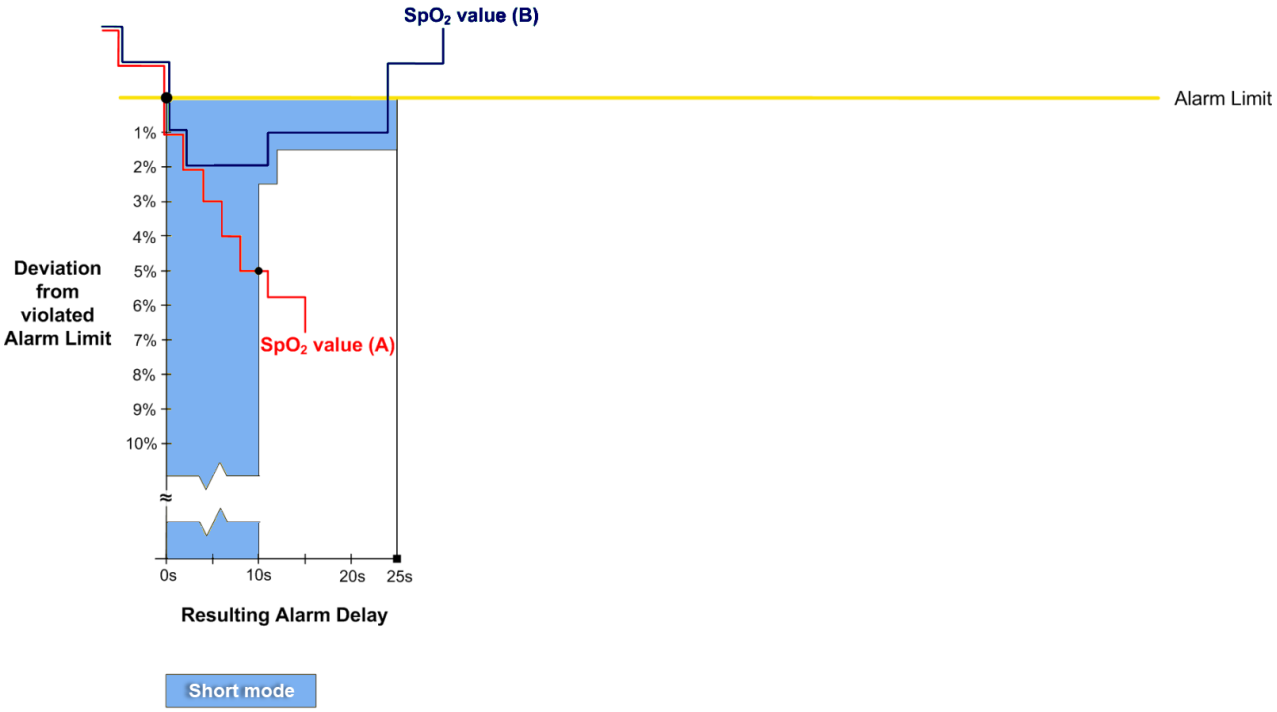


Figure 17: Example Smart Alarm Delay Short mode

This diagram shows the area for Short mode, with two examples of hypoxia.

Progressive hypoxia scenario: SpO_2 value (A) - the values drop steadily and after 10 seconds a value leaves the shaded area. An alarm is indicated immediately.

Recovery scenario: SpO_2 value (B) - the values stay within the shaded area for 24 seconds, deviating from the alarm limit by 1% or 2% before rising again above the alarm limit. No alarm is indicated because the SpO_2 values never leave the shaded area below the alarm limit.

On the basis of the two examples you can see the delay depends on how much the value exceeds the alarm limit, and for how long. Changes in the SpO_2 value can be major, but very short, or minor and for a long time - as long as they stay within the shaded area no alarm will be indicated.

Example with Medium mode

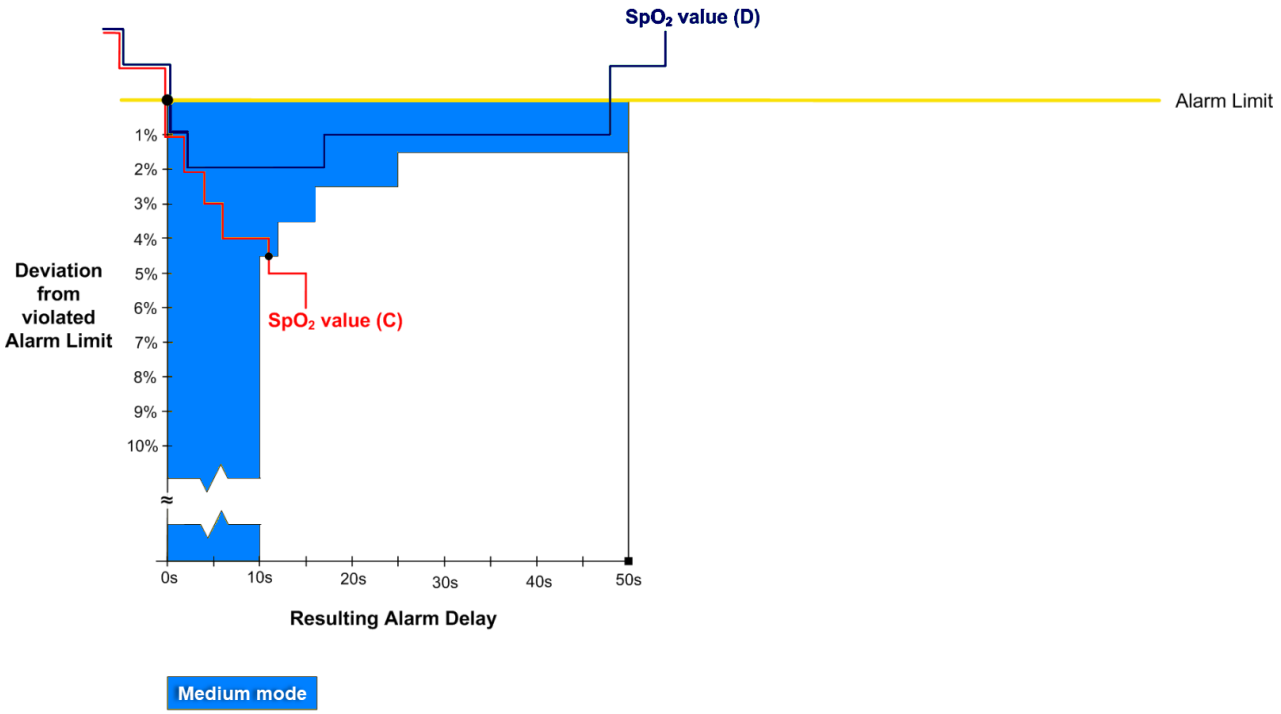


Figure 18: Example Smart Alarm Delay Medium mode

This diagram shows the area for Medium mode, with two examples of hypoxia.

Progressive hypoxia scenario: SpO_2 value (C) - the values drop steadily and after 11 seconds a value leaves the shaded area. An alarm is indicated immediately.

Recovery scenario: SpO_2 value (D) - the values stay within the shaded area for 48 seconds, deviating from the alarm limit by 1% or 2% before rising again above the alarm limit. No alarm is indicated because the SpO_2 values never leave the shaded area below the alarm limit.

Example with Long mode

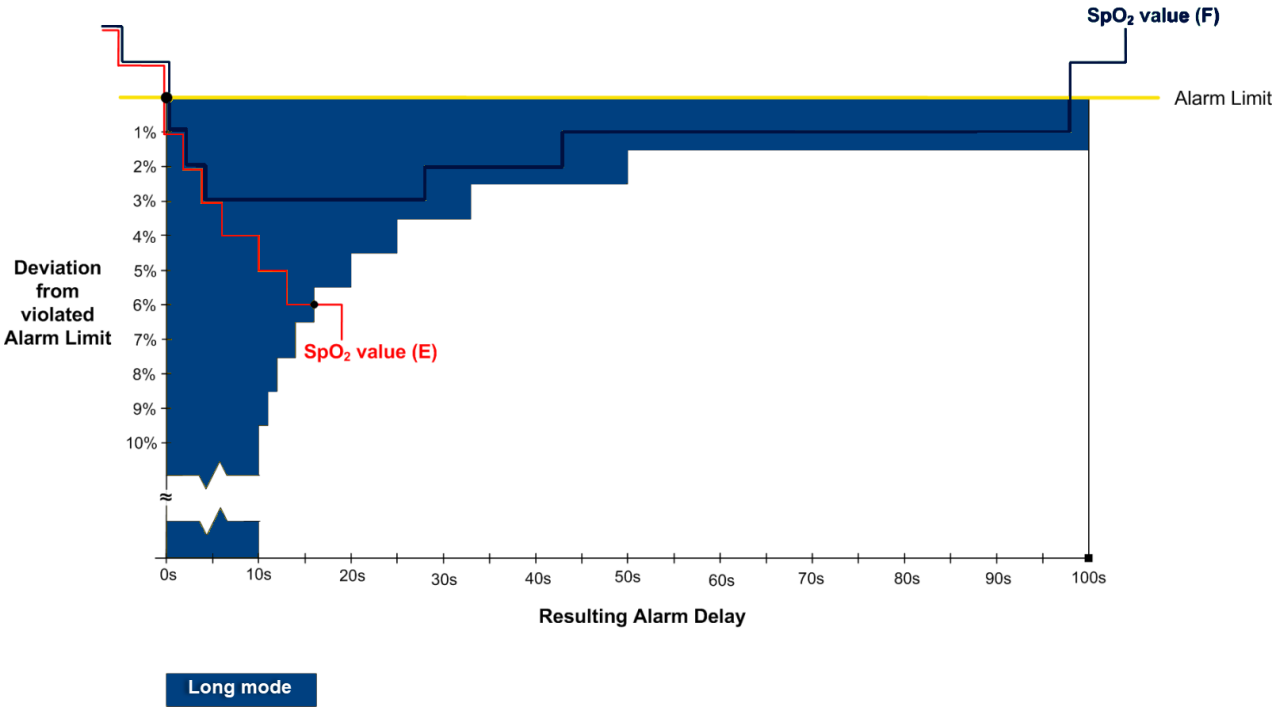


Figure 19: Example Smart Alarm Delay Long mode

This diagram shows the area for Long mode, with two examples of hypoxia.

Progressive hypoxia scenario: SpO_2 value (E) - the values drop steadily and after 16 seconds a value leaves the shaded area. An alarm is indicated immediately.

Recovery scenario: SpO_2 value (F) - the values stay within the shaded area for 98 seconds, deviating from the alarm limit by 1% to 3% before rising again above the alarm limit. No alarm is indicated because the SpO_2 value never leaves the shaded area below the alarm limit.

The Smart Alarm Delay applies only to the high and low alarm delay. The Desat alarm delay is a pre-configured time and is not affected by the Smart Alarm Delay.

SpO_2 Trending on the IntelliVue Patient Monitor

IntelliVue SpO_2 Trend Overview

Numeric trends are extremely flexible, displaying anywhere from 30 minutes to 12 hours of patient data without disrupting or obscuring realtime measurements. Three different formats - graphical, tabular and horizon - are available.

Trends are patient data collected over time and displayed in graphic, tabular, horizon, or histogram form to give you a picture of how your patient's condition is developing. Trend information is stored in the trends database for continuously monitored measurements, as well as for aperiodically measured parameters.

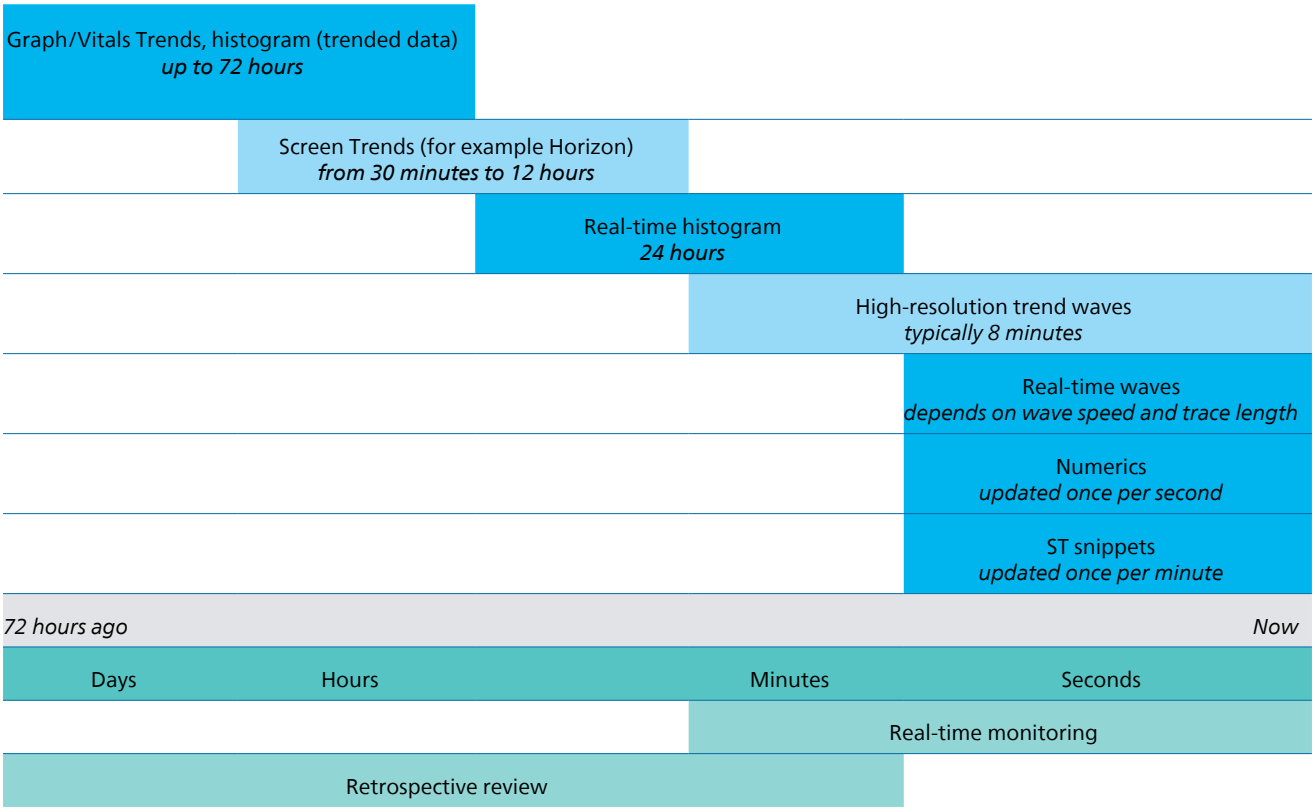
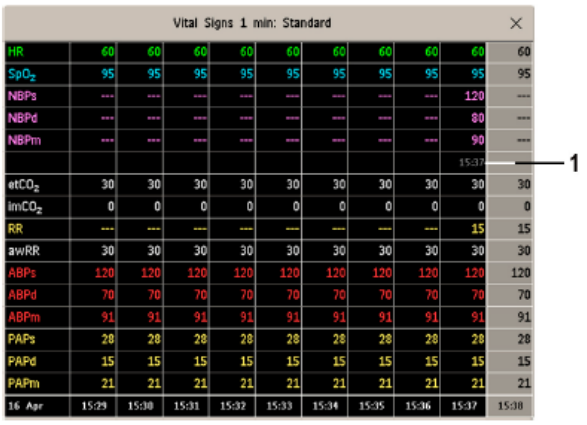


Table 6: IntelliVue Trend overview

Trend information can be viewed embedded as a screen element on specially designed screens, or you can open a trend window over the current screen.

Graphic and tabular Vital Signs trends

The trend windows open displaying the most recent data and are updated as new data is stored. A timescale along the bottom or at the top of the screen shows where you are in the trends database. Any values available for display before the next scheduled update are shown in the right hand column, with a timestamp in brackets.



1 - Aperiodic values are shown with a timestamp

Figure 20: Tabular Vital Signs trend view

In graphic trend view a cursor spanning all measurements in the trend group helps you to navigate through the trends database and shows you your current position in the database. When the cursor is moved across the time line, the values measured at the cursor time are shown in the right hand column. In graphical trends, aperiodic measurements are shown as an asterisk, NBP has a special symbol.

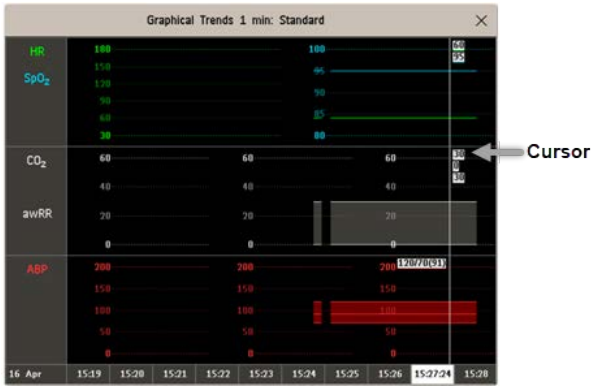


Figure 21: Graphic Vital Signs trend view

Horizon trend

The horizon view presents trend information superimposed over a defined baseline or base range. This helps healthcare professionals visualize changes in the patient's condition since the baseline was set.

Display of a parameter in Horizon trend has different components:

- **A horizon drawn in white**, as reference point or baseline to help you visualize changes in the patient's condition. The horizon can be set to represent the patient's current condition, or a target condition and can be a single value or a range.
- **A deviation bar**, showing how the currently measured value deviates from the set horizon. The height of the deviation bar is an indication of the extent of the change in the patient's condition relative to the (horizon) baseline.
- **The trend indicator arrow**, indicating how the patient trend has developed in the set time period (10 minutes, 5 minutes or 2 minutes).

The horizon is the reference value to which the deviations in the measurements are compared. You can set a high and low horizon to select the upper and lower horizon value as target values (B). If the high and low values are the same, the horizon is a baseline (A). With the auto horizon function, the currently measured value is set as the baseline.

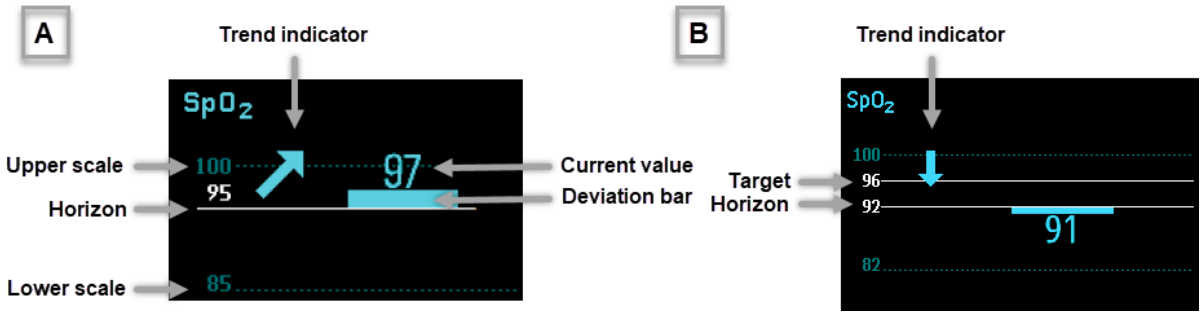


Figure 22: Horizon trend example

The direction of the trend indicator arrow reflects the ascent or descent of the regression line that is determined by the scale. There are 5 possible directions for the indicator.

Trend indicator	Description
	Ascent/descent greater than 15% in the last 10 minutes
	Ascent/descent between 5% and 15% in the last 10 minutes
	Ascent/descent less than 5% in the last 10 minutes

Table 7: Horizon trend indicator arrow directions

Depending on how the monitor is configured, Horizon trends can also display a graphical trend with a trend time line (from 30 minutes to 12 hours).

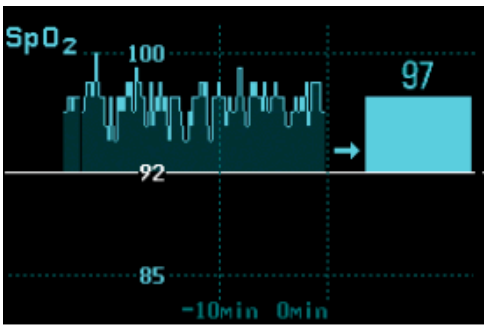


Figure 23: Horizon trend with graphical trend example

Histogram trends

A histogram is a graphical presentation of the distribution of the measured SpO_2 values during a time period. The title line of the window shows the label of the trended measurement, the period of time, and the resolution of the data, in this example the last 12 hours and a resolution of 1 second is selected. The horizontal axis shows the range and unit of the SpO_2. The vertical axis shows the percentage of time. The columns in the foreground show how much of the time the measured SpO_2 fell into this range on the scale. For example, in the histogram below the SpO_2 value was between 93% and 94% during 20% of the last 12 hours.

The arrow mark over the column shows that the currently measured value is in this range.

The columns in the background show the cumulative percentage value: each of the foreground columns is added to the sum of those columns to the left of it. The display of the percentage value above each column (cumulative curve), can be switched on or off. A question mark is displayed if less than two-thirds of the data are valid samples.

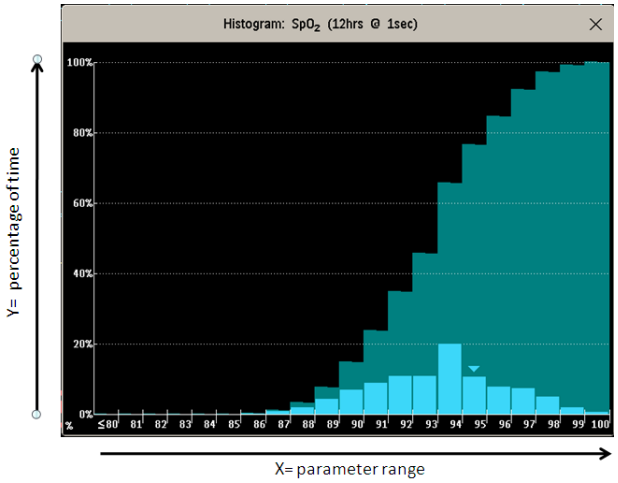


Figure 24: Histogram trend example

The advantage of the histogram view is that the largest and smallest ranges also give an immediate impression of the frequency of distribution.

In the advanced Cursor menu you can set two cursors that span a "corridor", for example to divide a histogram into in-range and out-range areas. Define your upper and lower range, and the distribution of the measured SpO_2 values within and outside the ranges in percentage of time are automatically calculated and displayed. Color shading is used to differentiate the ranges in the cumulative column and to highlight the columns between the cursors.

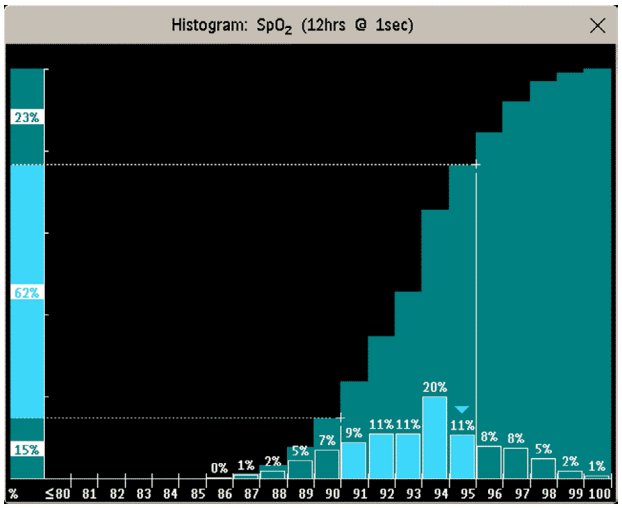


Figure 25: Advanced histogram trend view

Histograms may be useful in evaluating the pre-term infant in acute care phases as well as assist in discharge readiness and planning. Histograms may also support you in optimizing oxygen and ventilator settings. Oxygen and CO_2 allow a quantitative assessment of respiratory management.

Additionally, the histogram allows a quantitative assessment of patient's response to administered medication.

The SpO_2 histogram can be displayed in an embedded screen element, or viewed in a separate pop-up window.

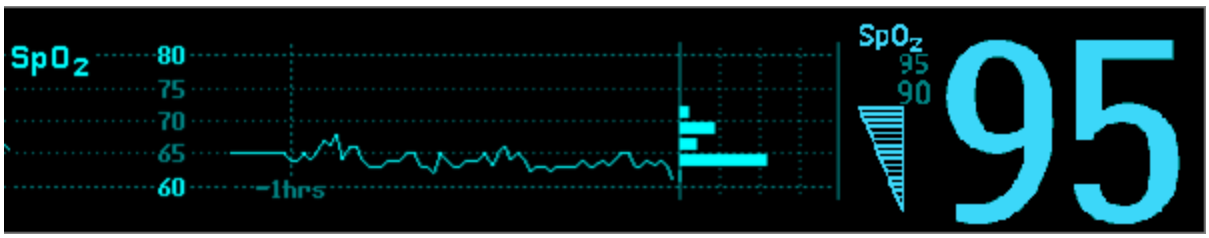


Figure 26: Customized histogram trend view

The histogram is also available for other measurements.

SpO_2 included in Clinical Decision Support tools in neonatal surveillance

Monitoring SpO_2 is an important measurement in neonatal surveillance. Both too little and too much oxygen is dangerous for neonates, particularly for premature neonates [6].

Pre- and post-ductal SpO_2

When monitoring pre and post-ductal SpO_2 in pre-term neonates, for example to identify right to left ductal shunting [7] or for critical congenital heart disease (CCHD) screening [8], it is important to place the sensor at the site relevant to the ductus arteriosus (right hand, or thumb of the right hand = pre-ductal; right or left foot = post-ductal).

Monitoring dual SpO_2

With a second SpO_2 measurement the monitor displays both SpO_2 values and pleth waves. With the delta SpO_2, the monitor calculates the difference between them. The second value is subtracted from the first. In the setup ΔSpO_2 menu you can choose the measurement source for the first and the second SpO_2.

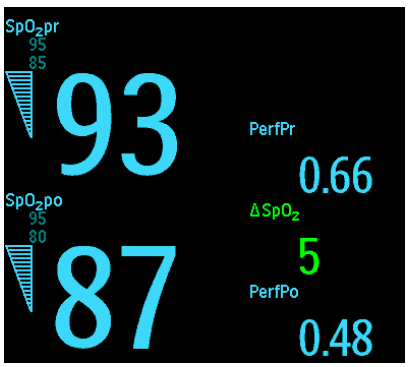


Figure 27: Example monitoring dual SpO_2

High resolution trends (OxyCRG)

For neonatal surveillance, a specially designed screen called OxyCRG is available. The OxyCRG consists of compressed trends of the neonate's beat-to-beat heart rate, respiratory waveform and oxygenation status; giving a more comprehensive picture of the neonate's condition in the preceding six minutes. With a continuous OxyCRG display it is easier for clinicians to detect and view the beginning of events such as bradycardia. The high resolution measurement samples are taken at a resolution of four samples per second.

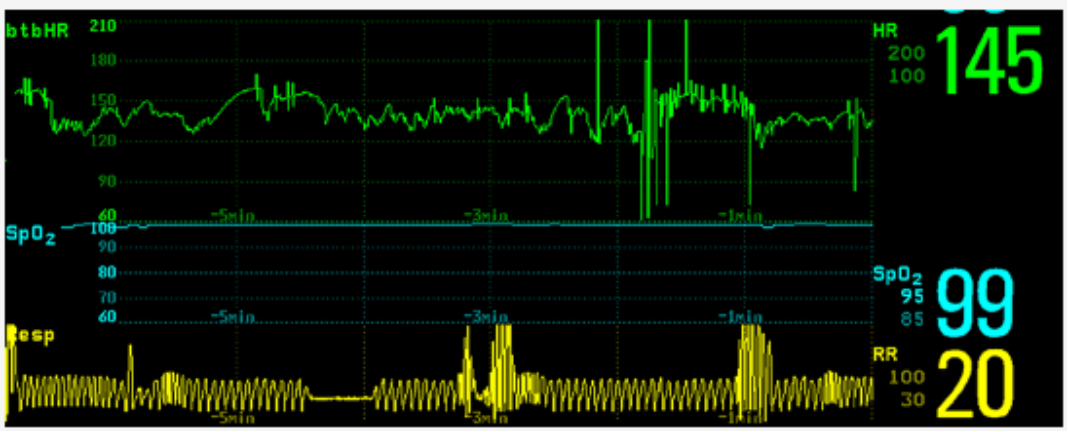


Figure 28: OxyCRG high resolution trend

Neonatal Event Review (NER)

Documentation of neonatal events can be important to diagnose and manage the patient. The correlation of apnea, bradycardia and drops in oxygenation, number, severity and distribution of events can help to identify the underlying disease and therefore the appropriate course of treatment.

The Neonatal Event Review on IntelliVue patient monitors can address all needs for automated event review and documentation across the care levels.

The application includes the following features:

- Automatic event detection and storage
- A 24-hour Neonatal Event Review window with Event Summary
- A 4 minute OxyCRG episode stored for each reviewable event in an OxyCRG Episode window
- Event storage for triggered criteria, either a specified alarm condition or user defined criteria.

Understanding the Event Review window

Vertical bars mark the events in the event review. The time line shows the position of the stored events.

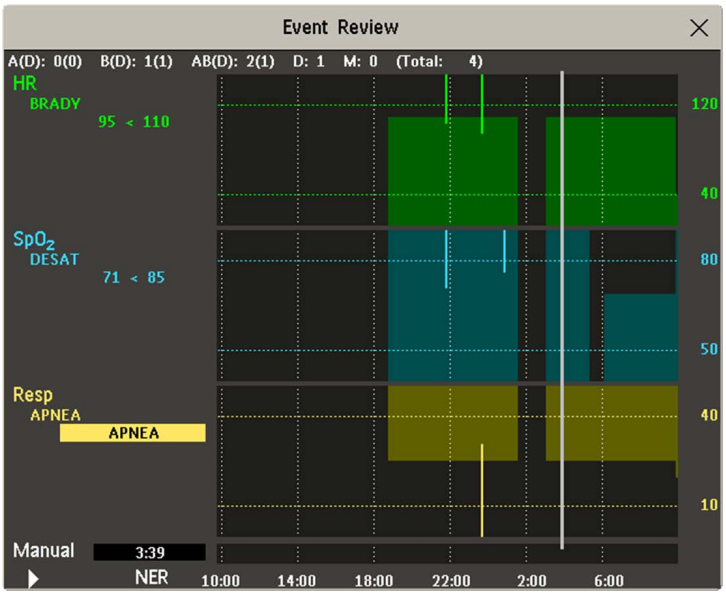


Figure 29: Event Review window

Each colored event bar represents one event. The height indicates the event severity. Bars that extend over more than one channel represent combi events.

Information for the currently selected event is shown on the left side of the window. The trigger measurement is highlighted.

Events are counted and classified by the event counter: apnea events (A), bradycardia events (B), and combinations of these events (AB). If they are associated with a desaturation (D), this is also marked. For example A(D): 2(1) indicates that two apnea events occurred and one of them was associated with a desaturation.

Reviewing stored events

The event episode window shows:

- the event trigger highlighted
- the event time,
- a high resolution trend of two minutes before and two minutes after the event (factory default)

The cursor lets you navigate along the time line. Selecting the pop-up key **Vitals View** changes the view from graphical to tabular.

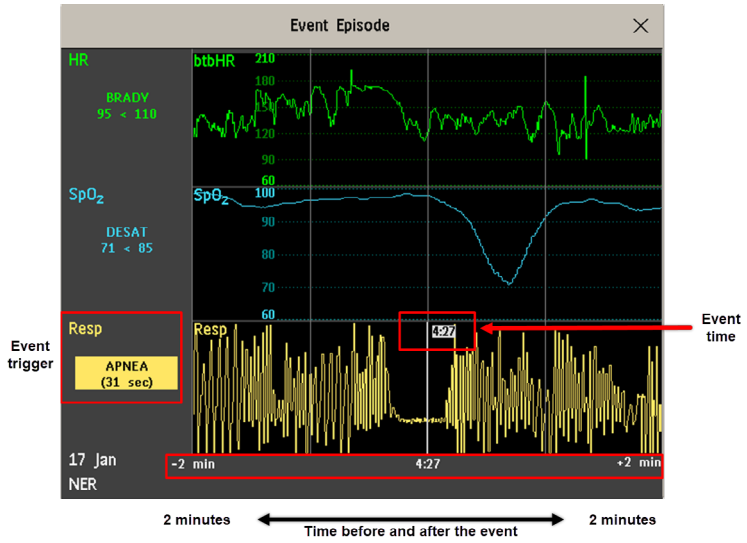


Figure 30: Event Episode window

The maximum number of events that can be stored in the event database depends on the configuration and the level of event surveillance.

Events are stored in the monitor's event database for the configured lifetime, either 8 hours or 24 hours. Deleted events cannot be retrieved.

CAR test

In some countries, prior to hospital discharge the Car Safety Seat Assessment Record is recommended for all pre-term babies under 37 weeks gestation or 2500 grams birth weight [9]. The car seat test verifies that premature babies are able to sit in a car seat safely, without any episodes of desaturation, apnea or bradycardia. The CAR application in the IntelliVue patient monitor provides the hospital with a method to easily institute this testing recommendation, or their own discharge criteria according to their policy and procedure.

The Car Safety Seat Assessment Record (CAR) on IntelliVue monitors is based on the Neonatal Event Review (NER). The CAR application utilizes the NER to capture bradycardia, apnea and desaturation events. A real-time histogram shows the distribution of the measured SpO_2 during the defined period of time.

The CAR application monitors the pre-term neonate for a selected period of time using a specially designed screen. It provides a three page report with the neonatal event review and event details, including the SpO_2 histogram.

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