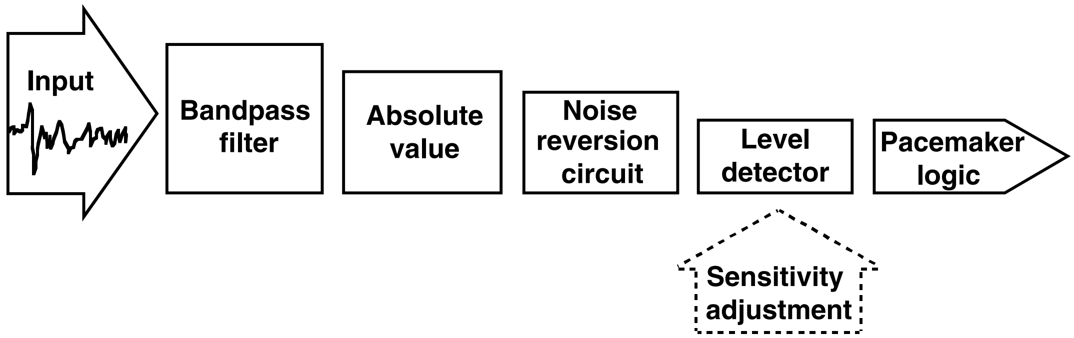
Pacemaker sensing circuits amplify, filter and either process or reject incoming signals



Sensing is the ability of the pacemaker to detect the intrinsic heartbeat and respond by sending or not sending (inhibiting) the scheduled pacing impulse to the heart.

To sense, a pacemaker sends the electrogram (intracardiac electrical signal) from the tip electrode to the ***sensing circuits***.* There, signals are processed and compared with the programmed sensing threshold. Signals with an amplitude greater than the threshold are admitted and sent to the timing circuits. The remaining signals are discarded as noise. Noise is any extraneous electrical signal that may inappropriately inhibit or delay delivery of the pacing pulse (see figure).

Sensing circuits are composed of several units, including an amplifier, bandpass filter, and level detector. Each uses different criteria to process the intracardiac signal. Pacemakers also have a noise reversion circuit that looks for repetitions of a certain signal type. If noise is repetitive, the pacemaker reverts to asynchronous pacing (pacing without sensing) to protect the patient from inappropriate inhibition or delay of the pacing pulse (see figure).

*Dual chamber systems have one sensing channel for the atrium and another for the ventricle.

Notes

Accurate sensing results in the delivery of appropriately timed pacing pulses in the absence of intrinsic activity and inhibition of the pacing pulse when the heart is beating on its own.

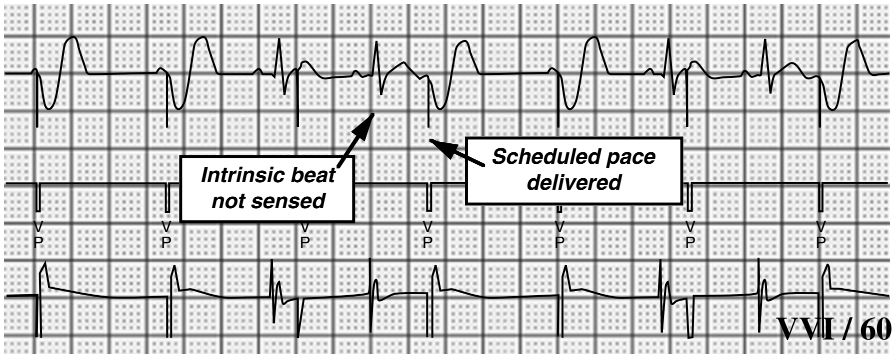
Question:

Electrical signals sensed at the tip electrode are processed by ______________.

Answer: sensing circuits

Undersensing

Pacemaker does not "see" the intrinsic beat, and therefore does not respond appropriately



Undersensing is the failure of the sensing circuit to detect intrinsic cardiac activity.

> ***Undersensing*** can lead to competitive pacing, a condition in which the pacemaker competes with the heart by delivering an unnecessary pacing impulse. The extra pulse could start an arrhythmia if it is delivered during the relative refractory portion of the recovery phase of action potential.

Notes

Undersensing results in the delivery of unnecessary pacing pulse, which could trigger dangerous arrhythmias.

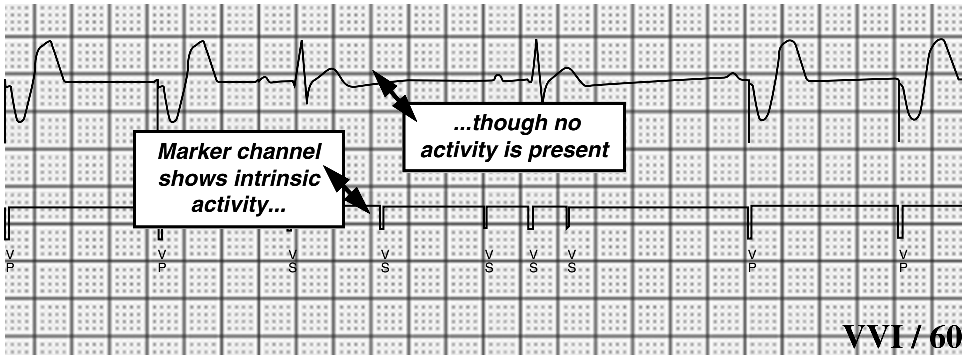
Question:

Competitive pacing may result from ________________.

Answer: undersensing

Oversensing

An electrical signal other than the intended P- or R-wave is detected



Oversensing is the sensing of events other than intrinsic depolarization.

Pacemakers are susceptible to ***far-field sensing***, the sensing of signals that originate distant to the tip electrode. These include:

- Atrial sensing of the R-wave or T-wave.
- Atrial sensing of the ventricular output pulse
- Ventricular sensing of the atrial output pulse, (called crosstalk).
- Sensing of muscle signals (called skeletal myopotentials) that originate from the depolarization of muscles near the heart or pacemaker. Unipolar leads are more susceptible than bipolar leads because of the greater distance between the anode and cathode.

Oversensing may also be due to:

- Atrial or ventricular sensing of their own output pulse.
- Ventricular sensing of the T-wave.

Note: See Medtronic Pacing Glossary for a definition of marker channels.

Notes

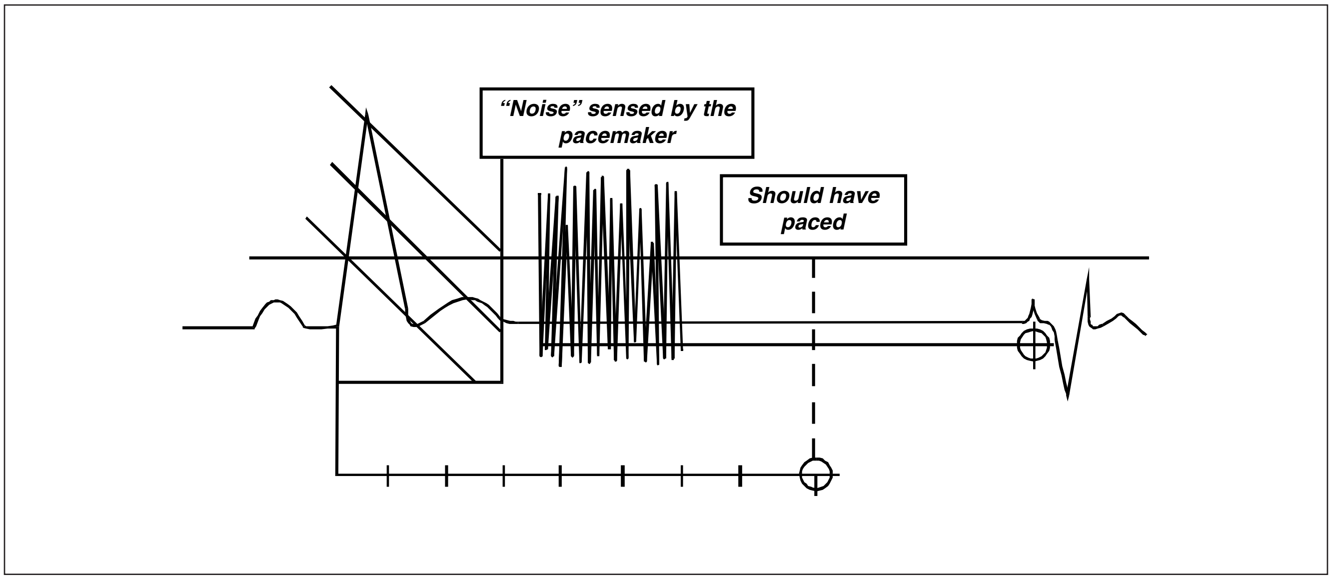
Oversensing results in the inappropriate delay or inhibition of a pacing pulse.

Question:

Signals that originate distant to the tip electrode are called ______________.

Answer: far-field signals

Electromagnetic Interference



Electromagnetic interference is the detection of non physiologic signals (electrical noise) from various sources.

Electromagnetic interference (EMI) is associated with electromagnetic fields in the range of 50 to 60 Hz. Exposure may inappropriately inhibit pacing in single chamber systems, produce high pacing rates in dual chamber systems, reset the pacer to an asynchronous mode, or permanently damage pacemaker circuits.

Pacemakers are protected from EMI by shielding, improved lead design, and filtering. EMI in home and office environments is unlikely. Possible sources of EMI in hospital environments are electrocautery (most common), transthoracic defibrillation, extracorporeal shock wave lithotripsy, radiation, radiofrequency ablation, transcutaneous electrical nerve stimulation (TENS), or an implanted cardioverter defibrillator (ICD). Precautions are taken during hospital procedures to protect the patient and pacing system.

EMI has been linked to the use of some cellular phones. EMI can be prevented by maintaining at least a 6-inch separation between the phone and IPG implant site. If interference does occur, moving the cellular phone away from the IPG restores normal function.

Notes

Questions:

Oversensing of non physiologic signals is called ______________.

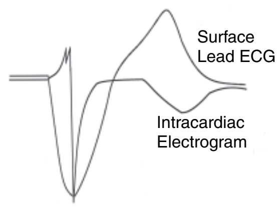
The most common source of EMI is ______________.

Answers: electromagnetic interference / electrocautery

Signal Characteristics

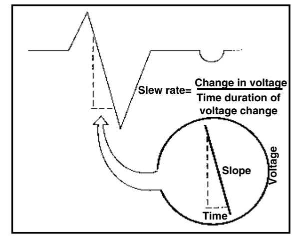
An Electrogram (EGM) is the Recording of Cardiac Waveforms Taken From Within the Heart

- **Intrinsic deflection on an EGM occurs when a depolarization wave passes directly under the electrodes**
- **Two characteristics of the EGM are:**
  - **Signal amplitude**
  - **Slew rate**



Slew Rate of the EGM Signal Measures the Change in Voltage with Respect to the Change in Time

- **The longer the signal takes to move from peak to peak:**
  - **The lower the slew rate**
  - **The flatter the signal**
- **Higher slew rates (number in mV) translate to greater sensing**
  - **Measured in volts per second**



An electric signal has two characteristics important for sensing: amplitude and slew rate.

Amplitude is the peak-to-peak voltage of an electrical signal, measured in millivolts (mV).

Slew rate (slope of the intrinsic deflection) is the rate the signal amplitude (volts) changes. Slew rate = change in amplitude (V) ÷ time. It is expressed in volts per second.

The less time it takes for an electrical signal to move from peak to peak, the higher the slew rate and the sharper the signal. The sharper the signal, the more likely it is to be sensed.

Notes

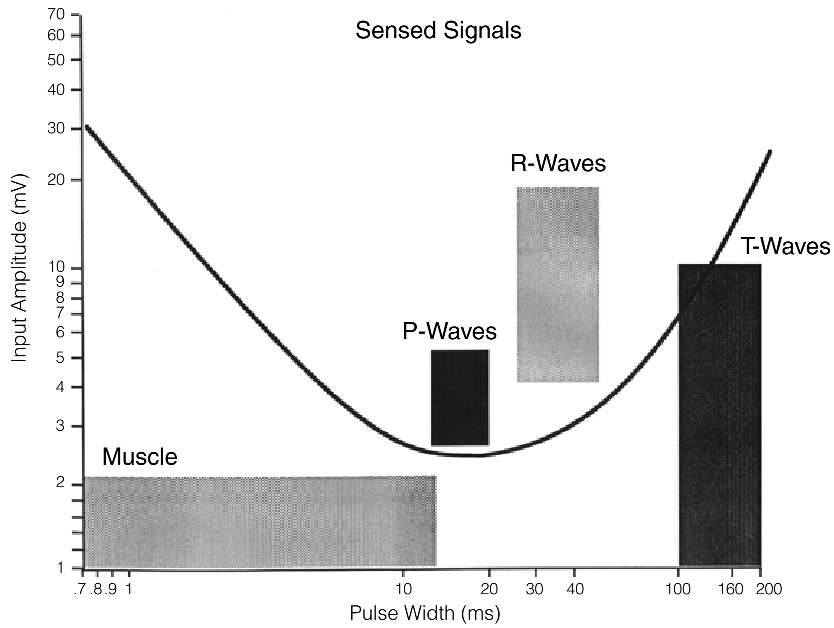
Questions:

The peak- to- peak voltage of an electrical signal is the ____________.

The rate at which the signal amplitude (V) changes is the ____________.

Answers: amplitude / slew rate

Signal Processing



The sensing circuit filters sensed signals on the basis of frequency content and eliminates those outside a certain range.

> ***Frequency content*** is the number of repetitions of a wave in a given period of time. It is measured in hertz (Hz), cycles per second. The dominant frequencies of P- and R-waves range from 10 to 30 Hz.
>
> The bandpass filter of most sensing circuits is designed so that frequencies above and below the center (parabolic curve in illustration) are attenuated (the amplitude is reduced). High slew rates have a high frequency content, and broad signals with low slew rates are not sensed, even if the amplitude is large. Filtering removes low frequency signals, typical of T-waves, and high frequency signals, typical of skeletal myopotentials.
>
> **Note**: In addition to filtering, a pacemaker manages unwanted electrical signals by including blanking and refractory periods in their timing cycles. This topic is discussed in the last section of this module.

Notes

Question:

The bandpass filter differentiates between electrical signals on the basis of ____________.

Answer: frequency content

Typical Amplitude and Slew Rate Values

Amplitude		Slew Rate	
Acute Ventricle	7 to 15 mV	Acute Ventricle	0.8 to 2.0 v/sec
Acute Atrial	1.5 to 4 mV	Acute Atrial	0.5 to 1.7 v/sec
Chronic Ventricle	5 to 12 mV	Chronic Ventricle	0.6 to 1.5 v/sec
Chronic Atrial	1.0 to 3 mV	Chronic Atrial	0.5 to 1.5 v/sec

Amplitude and slew rates may vary during lead maturation, but generally recover and stabilize at a chronic level.

Normal slew rate values at implant should exceed 0.5 volts per second for P-waves and 0.75 volts per second for R-waves. Lower slew rates may indicate an electrode position unacceptable for accurate sensing.

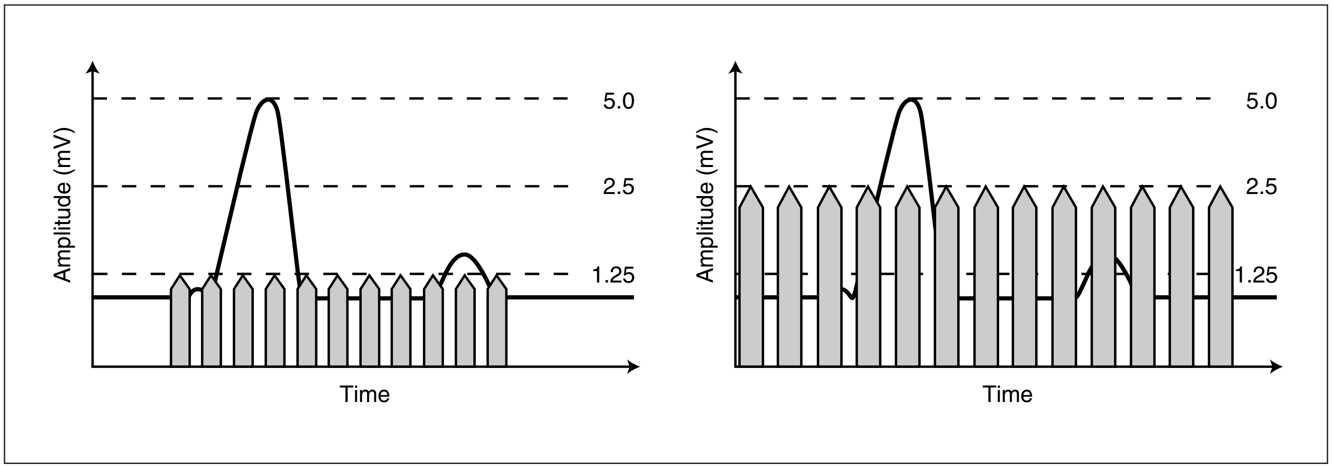
Notes

Question:

Acute atrial slew rates should measure > ______ v/sec.

Answer: 0.5

Sensitivity Setting



The level of sensing is controlled by the programmed sensitivity setting.

Sensitivity settings are graduated in millivolts (mV). The higher the numeric setting, the less sensitive the pacemaker is to intracardiac signals. The lower the setting, the more sensitive the pacemaker is. Thus, there is an inverse relationship between sensitivity and the numeric value of the sensitivity setting.

Sensitivity settings are like a fence: If the system is oversensing extraneous signals, the fence (numeric value) is raised to screen out more of the sensed electrical signal. If the system is undersensing intrinsic cardiac activity, the fence is lowered to reveal more of the sensed signal.

Some pacemakers provide automatic sensing tests that may be used to evaluate the patient's intrinsic rate and identify the sensing threshold. The sensitivity value is optimally set at a level twice the sensing threshold. For example, if the P-wave sensing threshold is 1.0 mV, the sensitivity value is set to 0.5 mV.

Notes

The proper sensitivity setting prevents oversensing and undersensing and allows the intrinsic rate to occur as much as possible.

Circle correct answer:

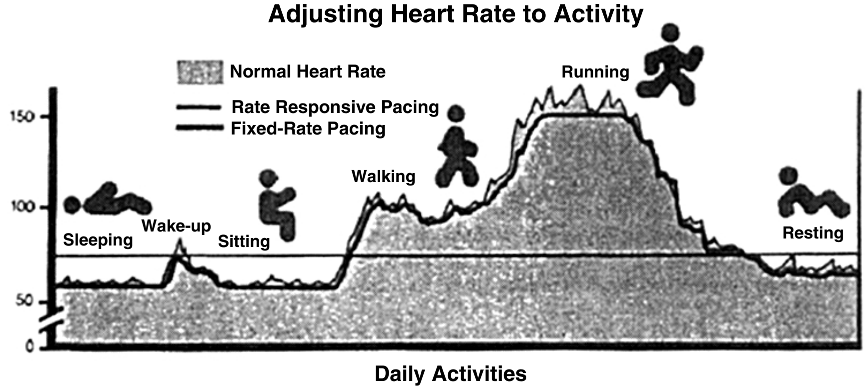
An intrinsic R-wave of 5.0 mV is recognized at a sensitivity setting of (2.5, 7.5) mV, but not at a sensitivity setting of (2.5, 7.5) mV.

Answer: 2.5 / 7.5

Rate Response

When the need for oxygenated blood increases, the pacemaker ensures that the heart rate increases to provide additional cardiac output

Adjusting Heart Rate to Activity



Rate responsive pacemakers seek to provide pacing rates proportionate to the patient's level of metabolic need.

Rate modulation or variation in a pacing system is accomplished through the use of one or more ***sensors***, which monitor physiological changes and determine the need for rate adjustments. The ideal physiological sensor is the sinus node. It responds quickly to increased metabolic need, is sensitive to exercise and non-exercise related changes, and is unaffected by stimuli that do not require an increase in pacing rate.

Modern sensors attempt to mimic the physiological response of the sinus node to exercise. Physiological optimization is balanced with technical requirements for sensor stability, small size, low energy consumption, biocompatibility, and ease of programming.

Note: See Cardiac Hemodynamics to review how heart rate and stroke volume increases affect cardiac output.

Notes

Rate response is modulation of the pacing rate in response to changes in measurable physiological parameters.

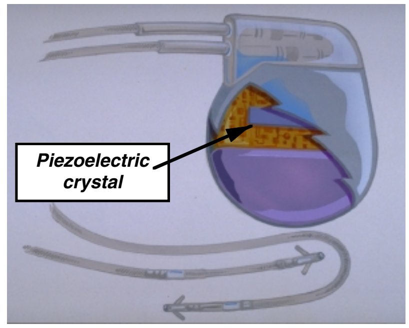
Question:

Sensors attempt to mimic the physiological response of the __________.

Answer: sinus node

Piezoelectric Crystal Sensor

- **Activity sensors employ a *piezoelectric crystal* that detects mechanical signals produced by movement**
- **The crystal translates the mechanical signals into electrical signals that in turn increase the rate of the pacemaker**



A piezoelectric crystal is an activity sensor that detects low frequency vibrations, which occur with increased body motion.

The ***piezoelectric crystal*** is bonded to the inside surface of the pacemaker can. The body vibrations produced by physical activity oscillate (vibrate) the can and bend the crystal. This produces a measurable electrical signal, which the pacemaker analyzes to determine the appropriate pacing rate.

Piezoelectric crystal sensors provide a rapid rate response to increased exercise, but do not respond directly to metabolic need. Thus, walking may lead to a greater rate increase than biking, because walking produces more vibration. Similarly, walking up stairs may produce a similar rate increase as walking down stairs, even though exercise workloads are significantly different. Piezoelectric crystal sensors are also susceptible to vibrations produced by direct pressure or nonexercise related motions, such as those produced when riding in a car.

Notes

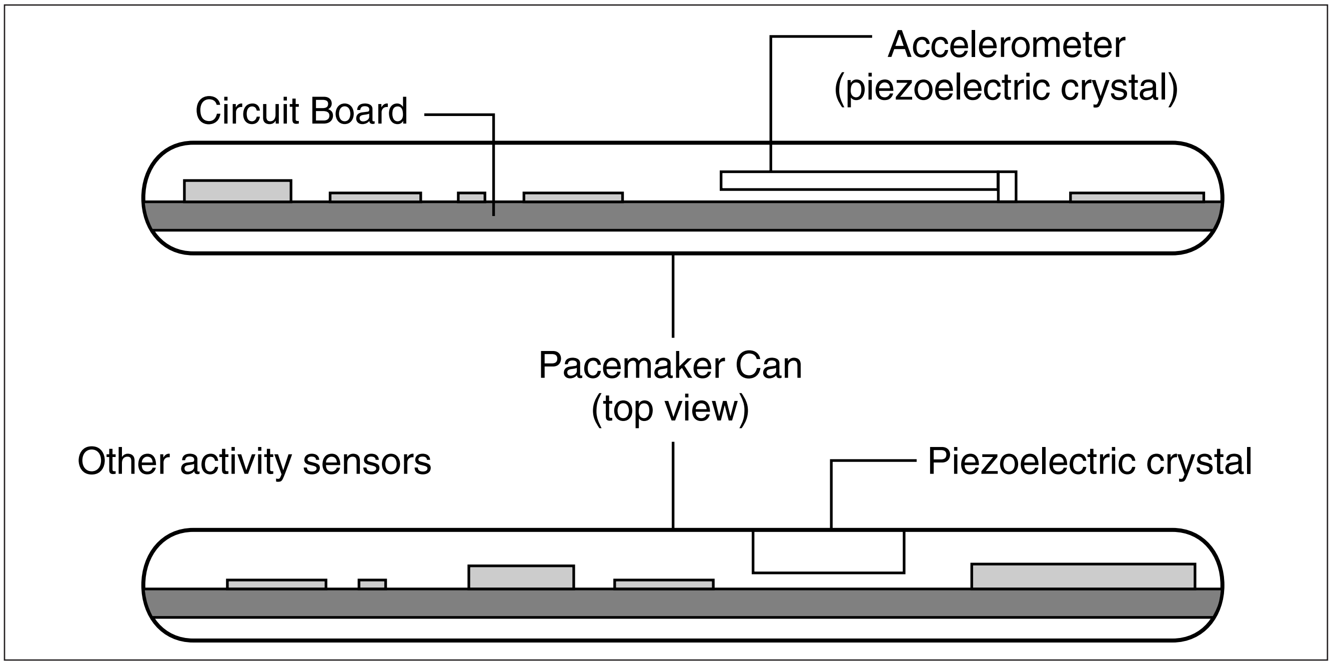
Piezoelectric crystal activity sensors respond rapidly to pressure waves caused by heel-strike activities.

Question:

A ________ sensor detects vibrations associated with increasing levels of exercise.

Answer: piezoelectric crystal

Accelerometer



An accelerometer is an activity sensor that is more sensitive to back and forth motion.

In an ***accelerometer***, the piezoelectric crystal is mounted on a circuit board rather than bonded to the pacemaker can. Body movement along the anterior-posterior axis causes the accelerometer to deflect in proportion to changes in velocity.

Because accelerometers are responsive to low frequency vibrations and anterior-posterior motion, they may provide appropriate rate increases for a wider variety of exercise workloads, including walking, biking, and stair climbing. Unlike the piezoelectric crystal sensor, an accelerometer is not susceptible to vibrations produced by direct pressure or nonexercise related motion.

Notes

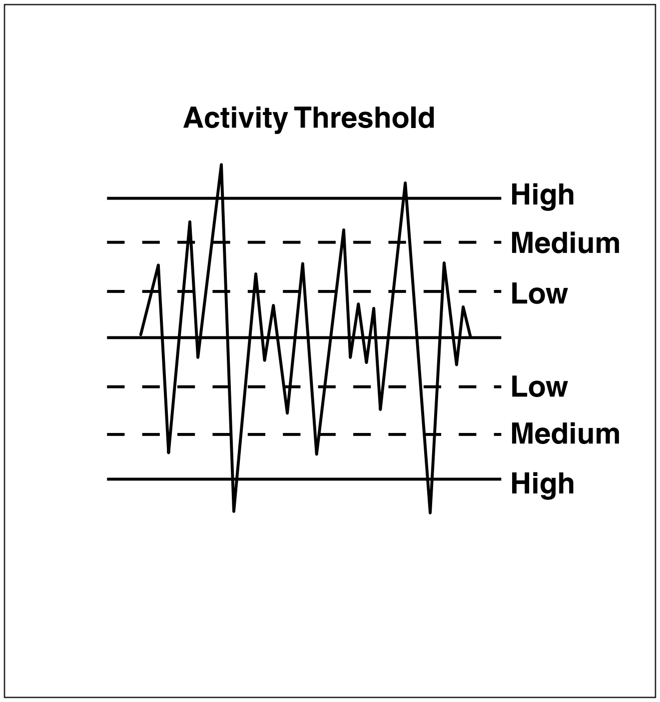
Accelerometers measure the movement of a small mass, as opposed to activity crystals which measure the movement of a large mass, the body.

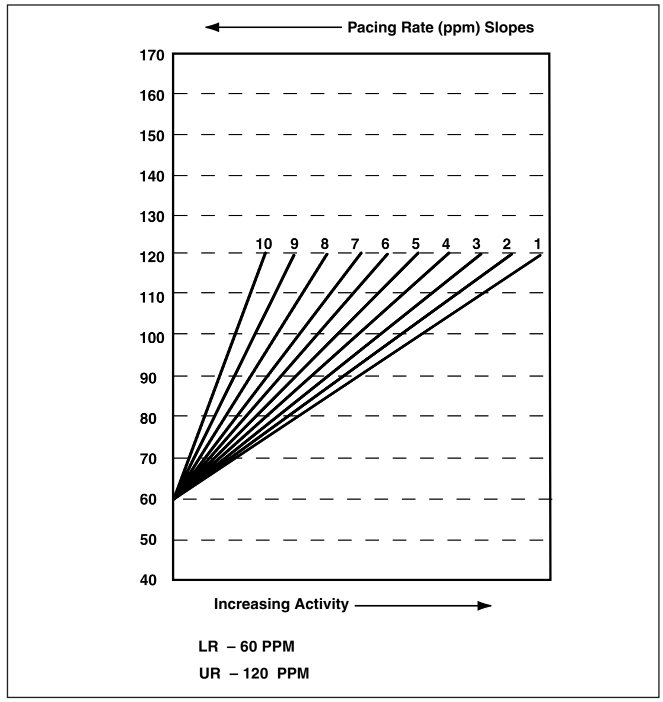
Question:

An ______________________ detects back and forth body movement.

Answer: accelerometer

Rate Response Settings





The pacemaker response to the sensor-indicated activity is controlled by the activity threshold, rate response slope, and acceleration/deceleration times.

Activity threshold settings range from low to high. At a low setting, the pacemaker increases the pacing rate in response to most physical activity (body motion), including that resulting from light exercise and environmental vibrations. At a high setting, the pacemaker increases the pacing rate only in response to more vigorous activity. The activity threshold interacts with the rate response slope and the acceleration and deceleration times.

The ***rate response slope*** determines *how much* the pacing rate increases or decreases in response to the detected level. The slope of activity is linear and ranges from gradual to steep (1 to 10). At a setting of 10, (most responsive setting), a small amount of activity increases the pacing rate.

The ***acceleration time*** is the time required to achieve approximately 90% of the difference between the current rate and a higher steady-state rate consistent with the current level of activity. It mimics the heart's fast response to increased metabolic need. ***Deceleration time*** determines how long it takes for the pacing rate to return from its upper value to its stable resting value. It represents the heart's gradual recovery from exertion.

Notes

Please see Medtronic Pacing Glosssary for definition of terms.

Questions:

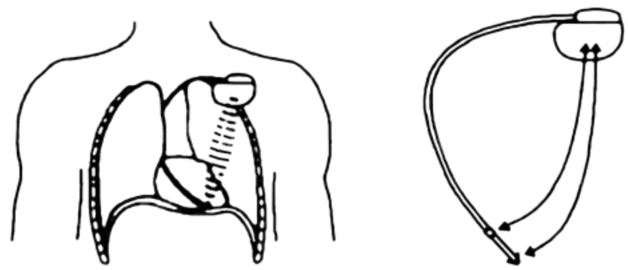
A high activity threshold makes the activity sensor (more, less) sensitive to body movement.

The ______________________ controls how much the pacing rate increases.

The ______________________ controls how quickly the pacing rate increases.

Answers: less / rate response slope / acceleration time

Minute ventilation can be determined by measuring the changes in electrical impedance across the chest cavity to calculate changes in lung volume over time.



Minute ventilation sensors measure changes in respiration rate (frequency) and tidal volume (depth).

Minute ventilation is the volume of air introduced into the lungs over time. Its two components are tidal volume, the amount of air brought into the lungs in one breath, and respiration rate, the number of respiration cycles (breaths) per minute.

A ***minute ventilation sensor*** measures changes in electrical impedance across the chest and calculates changes in lung volume over time - that is, it tracks the breathing rate and tidal volume. Respiration rate and tidal volume increase in proportion to changes in carbon dioxide production. Pacemakers with a minute ventilation sensor provide proportionate response to metabolic need over a variety of exercise levels.

Note: Please see Medtronic Pacing Glossary for definition of sensors.

Notes

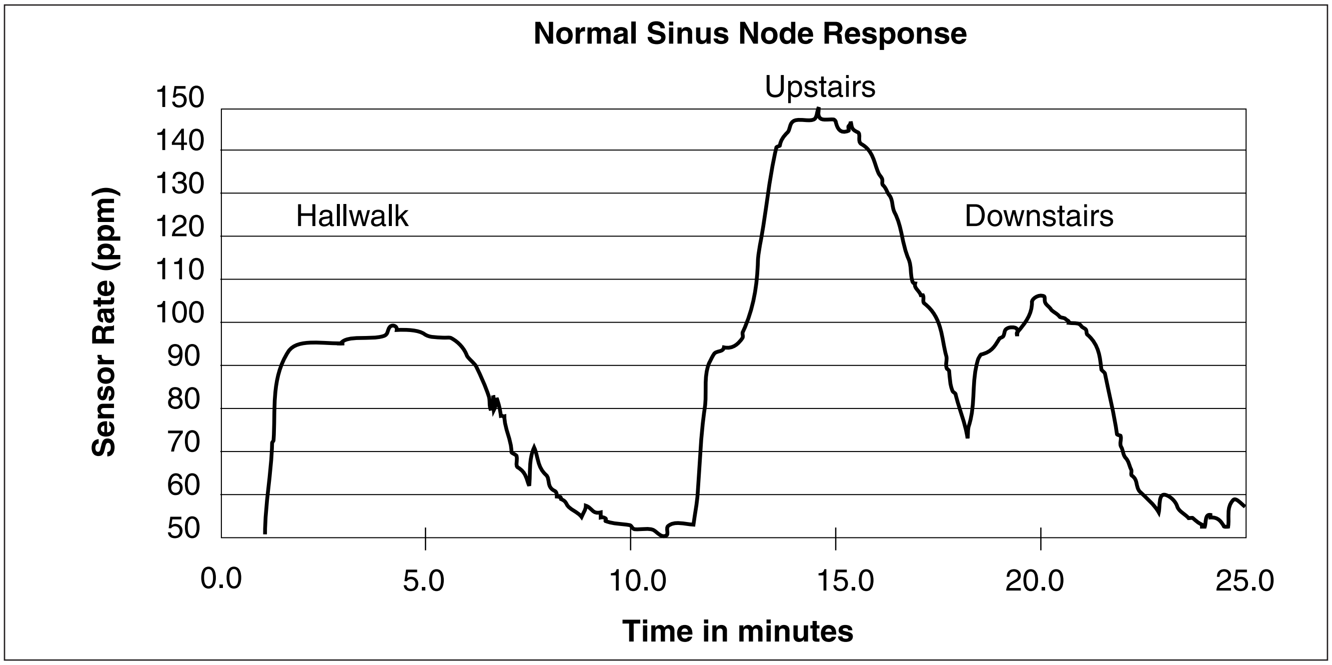
Minute ventilation sensors offer rate response proportional to metabolic demand.

Question:

A ____________________ sensor calculates changes in lung volume over time.

Answer: minute ventilation

Dual Sensors



Rate responsive pacemakers may use the strengths of two sensors to more closely approximate the normal sinus node response to exercise (see figure).

The goal of dual sensors is to provide prompt and proportionate rate response at a variety of exertional levels. The **activity sensor** responds quickly to physical exertion and is used to control the pacing rate at exercise onset. The **minute ventilation sensor** is slower to respond to physical exertion, but provides rate response proportional to metabolic need. It is used to control the pacing rate during sustained exercise.

Many different sensor combinations can potentially be integrated to overcome the inherent weaknesses of individual sensors.

Notes

Questions:

Prompt rate response is provided by an ______________.

Proportionate rate response is provided by a ______________.

Answers: activity sensor / minute ventilation sensor