

# Decreasing False Alarms by Obtaining the Best Signal and Minimizing Artifact from Physiological Sensors

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False alarms are all too common in medical monitoring.<sup>1,2</sup> Although caregivers commonly blame the monitor manufacturer, many problems can be prevented by careful and knowledgeable placement of the appropriate sensors.<sup>3</sup> Certainly, improved front-end monitor design and improved algorithms for artifact rejection and signal processing<sup>4</sup> will be helpful; however, caregivers can take measures to obtain a cleaner and improved input signal. Many caregivers have never been properly instructed in the correct way to apply monitoring sensors. Part of the blame may lie with the healthcare facility and part with the manufacturers, who have failed to inform users on how to get an optimal signal. In this article, we have drawn on our own experience and that of others to compile these suggestions.

## Electrodes

Surface electrodes are commonly used to measure electrocardiogram (ECG), electroencephalogram, evoked potentials, electromyogram, and more. For good signal processing, these electrodes should have as low an impedance as possible. Currently, two common kinds of electrodes are available: wet gel and hydrogel.

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Wet gel electrodes contain potassium chloride embedded in a gel typically at a concentration higher than hydrogel electrodes. Because the electrolyte is presented directly to the skin in a wet gel electrode, an acceptable signal can be acquired immediately after application.

Hydrogel electrodes absorb moisture over time from the patient's perspiration. As a result, it takes time for them to become moist and to reduce their impedance to acceptable levels.<sup>5</sup> Hydrogel electrodes tend to cause less skin irritation than wet gel electrodes (in part because of their lower electrolyte concentration), and they may be better suited for long-term monitoring.<sup>5,6</sup> It also is important to note that not all electrodes are magnetic

resonance imaging (MRI) compatible.<sup>7</sup> A few manufacturers offer MRI conditional and safe electrodes.<sup>5,8,9</sup>

Commonly, users place the electrodes as quickly as possible, with little attention to the impedance.

Further, inexpensive low-quality electrodes often are used.

Electrodes are

commonly supplied in bulk packs that once opened, allow the electrodes to dry out and thereby increase their impedance. Drying begins as soon as the pack is open, and

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If the patient will be moving, electrodes should be placed on areas of the body with minimum motion.

many electrodes lose substantial moisture within 24 hours.<sup>3,10-12</sup>

Better electrode impedance and performance can be obtained by:

- Using high-quality electrodes. If multiple electrodes must be tried (and time wasted) to get an acceptable signal, switching to more expensive, higher-quality electrodes probably would be cost effective.
- Avoiding hydrogel electrodes that depend on patient sweat to lower the impedance, if an immediate signal is needed. As noted, the impedance for these electrodes may not fall to an acceptable range until the electrodes have been attached for 20 minutes and have been wetted by the patient's perspiration.<sup>13</sup>
- Using smaller packs of electrodes rather than bulk packaging. In many hospitals, electrodes are stored in a plastic tray containing dozens of electrodes that have been dumped out of a sealed pack. Such electrodes will dry out quickly and thus have a high impedance. Although buying individually wrapped electrodes probably is not necessary (though these are available), buying packs of perhaps five electrodes<sup>14,15</sup> and using all of them before the next pack is opened seems prudent. Electrodes that have been opened (i.e., seal of pack has been broken) for more than 24 hours should be discarded. Of note, some manufacturers offer resealable electrode packs and these could be considered.
- Using electrodes from the same manufacturer and the same product line. If different kinds of electrodes are mixed, a "battery" effect with baseline shift of the signal can result and theoretically (though not likely) burn a patient. For the same reason, old and new electrodes should not be mixed.
- Taking care in placing electrodes on the body. When ECG electrodes are used for monitoring (as opposed to being used for diagnostic-quality ECG), electrodes should be placed in areas of decreased body hair, if possible. These areas are those where patients' clothes rub: the shoulders (over the deltoids) and the hips (where underwear waistbands rub). (These locations may be less useful if the patient is expected to be moving.) When necessary, hair can be shaved or clipped.

Ideally, patients would not be lying on the electrodes, as impedance can be affected when the pressure on the electrode changes from the patient moving positions.<sup>16</sup> Skin breakdown also is possible. ST segments can elevate or depress depending on the position of the patient.<sup>17</sup>

If the patient will be moving, electrodes should be placed on areas of the body with minimum motion. Electrodes placed in a grid over the rib cage will produce less motion artifact than electrodes on areas such as shoulders, upper arms, and thighs. This is the approach taken in cardiac stress testing, when the patient is walking on a treadmill.

Commercially available stickers with four to five electrodes built into a single sticker may be useful in some situations. These stickers are relatively expensive, however.<sup>14,15</sup>

Of note, a nonstandard electrode placement may be adequate for arrhythmia detection (including detection of ventricular and supraventricular arrhythmias), but standard electrode placement is needed for accurate detection of ST changes.

To avoid oily skin, the patient should be cleaned and prepped, if necessary. It was taught previously that the skin should be prepped with isopropyl alcohol or acetone. This practice is no longer recommended because the isopropyl alcohol or acetone dries the skin and increases the impedance. Instead, the present recommendation is to use soap and water, followed by a water rinse, followed by drying with a gauze pad, cloth towel, or paper towel, followed by air drying.<sup>5,10,15,18,19</sup> Alternatively, commercial abrasive skin preps ("liquid sandpaper"), or other skin preps that do not dry the skin, can be used.<sup>8,20</sup> The skin also can be abraded by rubbing lightly with fine sandpaper to remove the outer dead layer of epidermis (which has high impedance).<sup>6</sup>

For snap-on interfaces to electrodes, snap the wire onto the electrode before the electrode is applied to the patient. This technique is more comfortable for the patient, and in the case of wet gel electrodes, it prevents electrolyte dispersion, which can cause high impedance. (This issue is more important with snap-on electrode leads and less important with clip-on electrode leads.)

Press on the *edges* of the wet gel electrode to make good contact between the adhesive and

the skin, not on the center of the electrode. Again, the issue is avoiding gel dispersion. (Some electrodes are designed so that the snap is not located over the gel but rather is offset.)

Replace electrodes after 24 hours of use or per the manufacturer's recommendations. (This idea may not be practical in neonates, infants, and children.<sup>10,12</sup>)

In patients who are having shoulder surgery, the arm lead often can be placed on the ipsilateral side of the patient's forehead, as the ECG signal usually is detectable on the forehead.<sup>21,22</sup>

In burn patients, needle electrodes may be required.<sup>23,24</sup>

### Diagnostic-Quality ECG Electrode Placement

Often ECG leads are placed in convenient positions rather than in "standard" positions. Use of standard ECG positions is necessary for proper interpretation of P waves, QRS complexes, and ST segments. Nonstandard positions may be acceptable for heart rate and for more casual monitoring.

Limb leads historically were placed on the wrists and ankles. In 1975, the American Heart Association recommended placing the limb lead electrodes distal to the shoulders and hips, but this recommendation has been questioned.<sup>25</sup> More distal placement probably is better than more proximal placement.

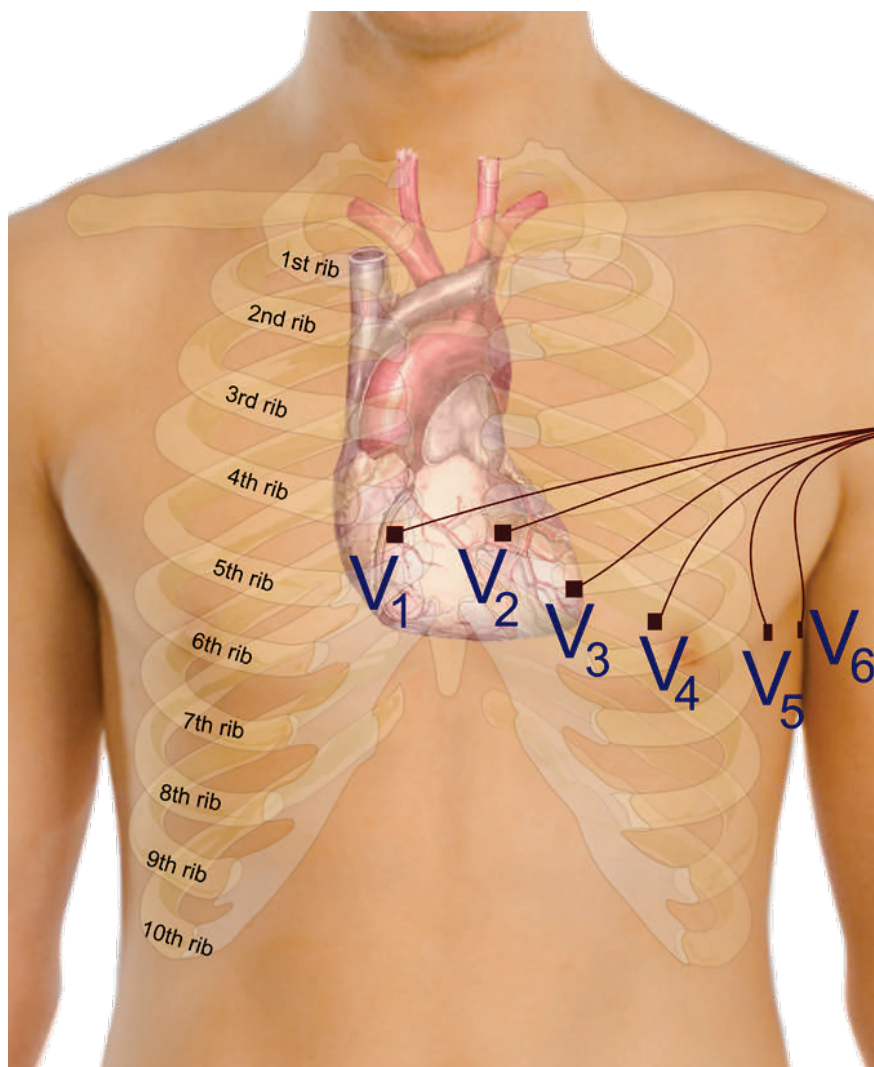
When diagnostic-quality ECG is required, the electrodes must be properly located in the classic literature positions. Accurate ST-wave analysis requires meticulous attention to proper placement. Placement of the chest leads requires counting and identifying the intercostal spaces. Few caregivers (and ECG technicians) actually count the intercostal spaces. Improper placement will give inaccurate ST readings. The standardized electrode placement has been reaffirmed by the American College of Cardiology and others.<sup>25</sup> The specific instructions for placing the V-leads are shown in Figure 1.<sup>26</sup>

Some hospitals have purchased ECG trunk cables that are specifically designed to be used with nonstandard ECG lead

## How to Place ECG Electrodes

- Locate the sternal angle (angle of Louis) between the manubrium and the body of the sternum. This is at the level of the second rib. The second intercostal space is just below the second rib.
- On the patient's right, slide your finger down two more interspaces, to the fourth intercostal space.
- V1 is located on the right sternal border at the fourth intercostal space.
- V2 is located on the left sternal border at the fourth intercostal space.
- (Skip V3 for now.)
- Slide your finger down one more space below V2, to the fifth intercostal space.
- Locate the midpoint of the patient's left clavicle. The left midclavicular line runs vertically through this point.
- With your finger, follow the left fifth intercostal space to the patient's left. V4 is located in the fifth intercostal space at the midclavicular line. (In female patients, this lead may need to be placed in the crease under the patient's breast.)
- V3 is located halfway between V2 and V4.
- From the position of V4, draw an imaginary horizontal line (or plane) through the patient's chest. Do *not* follow the intercostal space; use a horizontal line (or plane) from V4.
- (Skip V5 for now.)
- The midaxillary line is an imaginary line that runs down the middle of the axilla (i.e., the midpoint of the patient's lateral chest).
- V6 is placed at the same horizontal line as V4, at the midaxillary line.
- The anterior axillary line is an imaginary line that begins at the anterior crease of the axilla and runs vertically through this point.
- V5 is placed at the same horizontal level as V4, at the anterior axillary line.
- If the anterior axillary line is hard to identify, place V5 halfway between V4 and V6.

**Figure 1.** Placing electrodes. Image source: Wikimedia Commons



When diagnostic-quality ECG is required, the electrodes must be properly located in the classic literature positions. Accurate ST-wave analysis requires meticulous attention to proper placement.

placement systems. An example would be the Philips “EASI” lead system (Philips North America, Andover, MA).<sup>27</sup> Sometimes these hospitals are unaware that they have these special trunk cables or that a different electrode placement is required to obtain accurate ECG signals.

Caregivers often are unaware of appropriate settings for ECG processing within the monitor. For example, “diagnostic”-quality processing *must* be selected when a diagnostic-quality tracing is desired. For other applications, “monitoring”-quality processing may suffice—and may result in less artifact and fewer false alarms. Likewise, leads must be selected and configured correctly (e.g., for the “EASI” lead system, mentioned above). Caregivers should consult the manufacturer’s instructions for proper settings.

Some monitors count the heart rate and detect arrhythmias only on certain leads. Again, caregivers should check with the manufacturer to determine how the leads are processed. Sometimes the heart rate is counted from the top one or two leads that are selected to be displayed. In this case, one should pick the lead with the biggest upright QRS as the lead for heart rate counting and arrhythmia processing.

### Noninvasive Blood Pressure

In the best of circumstances, noninvasive blood pressure is accurate only to a standard error of  $\pm 10$  mm Hg, as compared with an invasive arterial cannula.<sup>28</sup> Several issues can contribute to inaccurate blood pressure readings and artifact.

First, use a cuff of the appropriate size. Many hospitals have switched to disposable cuffs, so that each patient has his/her own cuff for the entire hospital stay. Often, these cuffs are too small for an obese adult patient. Nearly all cuffs have index lines on the inside or the outside of the cuff, to indicate whether they are too large or too small. A cuff of the appropriate size should always be used. Further, some cuffs may be long enough to wrap around the arm and be within the appropriate index lines but too narrow (i.e., too short as they go up the arm from the elbow to the shoulder) to give accurate readings. A wider cuff (i.e., taller as it goes up the arm from the elbow to the shoulder)

should be used in obese patients. These cuffs are commonly called “large” adult cuffs and should be used in preference to a “long” adult cuff.<sup>29</sup>

The cuff should be neither too tight nor too loose. It should be possible for the caregiver to place one or two fingers between the cuff and the extremity.

The cuff must be checked at intervals, to be sure that it has not slipped down the arm. A cuff over the elbow can cause nerve injury.<sup>30</sup>

Rotate the cuff so that the center of the inflatable bladder of the cuff is over the artery. This point is sometimes marked on the cuff with an arrow or another symbol. The artery on the upper arm is medial (i.e., next to the chest when the arm is at the side, where one can feel the pulse at the mid-upper arm), *not* over the center of the biceps muscle.

Blood pressure must always be corrected to heart level; otherwise the reading will be incorrect. (see section on invasive blood pressures for details on heart level). The correction for hydrostatic pressure (from the geometric center of the cuff to heart level) is approximately 2 mm Hg per inch of height. That is, the blood pressure increases by approximately 2 mm Hg per inch of height when the cuff is below heart level and decreases by the same amount when the cuff is above heart level (Figure 2). For example, if the patient is in the lateral position, a cuff on the top arm may be 10 inches above the heart. In this case, the readings for systolic and diastolic blood pressure each will be 20 mm Hg lower than the true pressure at heart level.<sup>31</sup> Alarm limits should be adjusted to compensate for the hydrostatic pressure change.

In the operating room, consider the issue of surgeons who lean on the cuff during surgery, especially during neck or chest cases. One solution is to use a metal shield over the cuff. These shields commonly are used to help tuck the arms at the patient’s sides, but they also help prevent the surgeons from leaning on the cuff. An alternative is that often the cuff can be placed on the ankle, immediately above the malleoli, with the bladder of the cuff posterior, so that the surgeons will not lean on it. Of course, one must check that the patient does not have peripheral vascular disease or some other issue that might affect the ankle versus arm

blood pressure (or ankle-brachial index), and one must be sure that any hydrostatic difference (i.e., difference in height above the floor) is corrected, as above.<sup>32</sup>

Recognize that noninvasive blood pressure often will be inaccurate in the patient who is shivering or having seizures. Shivering and, of course, seizures should be treated. If the patient has a spinal or an epidural anesthetic in place, the ankle should not be shivering.

Noninvasive blood pressure also may be inaccurate in patients with arrhythmias: bradycardia (especially if the heart rate is below 40 or 50 mm Hg), atrial fibrillation, and frequent premature ventricular contractions. Arrhythmias may need to be corrected before accurate readings can be obtained.<sup>33</sup>

If the previous two points cannot be corrected, an invasive blood pressure should be used for accurate readings.

## Pulse Oximetry (SpO<sub>2</sub>)

### Finger Probes

Avoid placement of a finger probe on the same arm as a blood pressure cuff. When the cuff is inflated, it will temporarily occlude blood flow to the finger and interfere with the SpO<sub>2</sub> signal.

Do not place the finger probe on the thumb or index finger if the patient has a radial arterial cannula in that hand.

The typical 20-gauge arterial cannula may decrease the pressure in the radial artery and interfere with the signal.<sup>34,35</sup> Use the ring or small finger of that hand, or use the other hand.

Do not place the finger probe on the side of the hand near an intravenous (IV) infusion. For example, if the patient has an IV cannula near the thumb or on the radial side of the forearm, use the ring or small finger for the finger probe. The reason is that that side of the arm will be cooled by the IV infusion, even if the infusion goes through a fluid warmer and even if the fluid is flowing at a low rate. The cooling will cause vasoconstriction or, more specifically, arterial constriction,

resulting in a poorer signal.<sup>36,37</sup>

If the probe is on the hand, keep the hand close to, or above, heart level. If the hand is far below heart level, an interfering pulsatile venous signal can occur in some oximeters.<sup>38</sup>

Do not expect the oximeter probe to work on a cold extremity. In some cases, one may be able to use a warming blanket to warm the extremity.

Do not place the oximeter probe on nails with nail polish, nail paint, or artificial nails. Patients should be instructed to remove these, at least on one finger of each hand. Alternatively, a good signal often can be obtained by placing the probe “sideways” on the finger (i.e., so that the light travels from side to side in the finger, rather than going through the nail). (Manufacturers state that the probes are not designed and calibrated to be used sideways, but often they work anyway. Future research is needed to verify the accuracy of this approach, but in the experience of the authors, it is satisfactory.)

Impaired peripheral circulation sometimes can be handled by placing a digital nerve block with local anesthetic *without* epinephrine.

**Noninvasive blood pressure also may be inaccurate in patients with arrhythmias: bradycardia (especially if the heart rate is below 40 or 50 mm Hg), atrial fibrillation, and frequent premature ventricular contractions.**

The local anesthetic will cause arterial dilation and will improve the pulse signal.<sup>37</sup> (This technique is reserved for those skilled and credentialed in the administration of local anesthetics.)

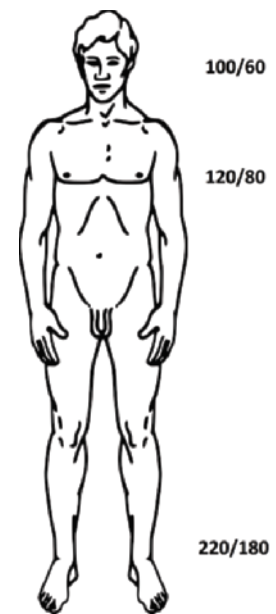
Do not place the oximeter probe on a hand with a muscle twitch stimulator or motor evoked potentials. The twitch artifact will interfere with the signal.

Do not allow sunlight or other bright lights to shine onto the probe.<sup>39</sup>

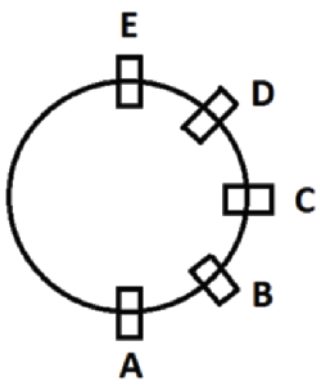
If using two oximeter probes, make sure that the light from one does not strike the sensor of the other. Separate them with opaque cloth if necessary.<sup>39</sup>

Do not rely on signals if the monitor indicates “low signal” or terms to that effect. Do not rely on these signals, regardless of whether the reading is high or low. Instead, find a spot with better signal strength.

Consider the use of later-generation



**Figure 2.** A standing adult. Approximate blood pressures at head level, heart level, and ankle level are shown in mm Hg. Figure outline from Pioneer Plaque Man as Diagram Template, by Mikael Häggström. Image source: Wikimedia Commons



**Figure 3.** Cross-sectional area of adapter for gas analyzer sampling tube. Five possible spatial orientations for the sampling connector are shown. Orientation A is most likely to entrain secretions into the sampling tube, as they will settle to the bottom because of gravity. Orientations D and E are usually the best. Orientations B and C are intermediate.

**A pulse oximeter probe designed for use on a finger also can be used on a toe.**

oximeters, which may give a good signal when older oximeters will not.<sup>40</sup>

### Ear Probes

Do not use a conventional pulse oximeter with an ear probe if the patient is in a horizontal or head-down position. In these situations, strong venous pulsation could confuse the oximeter, causing it to read falsely low. Ear probes often can be used in the patient who is sitting or in a head-up position. Rubbing the earlobe to make it hyperemic often will improve the signal for an ear probe. Later-generation oximeters may be useful if the patient is in a horizontal or head-down position.<sup>40</sup>

### Toe Probes

A pulse oximeter probe designed for use on a finger also can be used on a toe. A first-generation pulse oximeter, however, may read inaccurately if the patient is in head-up position or sitting or standing.

## Capnography and Other Respiratory Gas Analyses

### Intubated Patients

In an intubated patient, place the carbon dioxide (CO<sub>2</sub>) sampling connector as close to the connector of the endotracheal tube (or supralaryngeal airway) as possible.

If a heat and moisture exchanger (HME) (“artificial nose”) is used, the best signal will be obtained if the sampling connector is placed between the endotracheal tube and the HME, because of decreased dead space.<sup>41</sup> If, however, excessive secretions are blocking the sampling tubing or the sample line filter, the connector may be placed between the HME and the Y-piece. This position adds a small amount of additional dead space between the patient and the sampling point, but this is rarely clinically significant.

In selected patients, CO<sub>2</sub> sampling can be done with special endotracheal tubes with a separate CO<sub>2</sub> connector that goes down to the tip of the endotracheal tube.<sup>42–44</sup>

If an intubated patient has lots of secretions that are clogging the sampling line, try rotating the sampling adapter to different angles. Some angles allow fewer secretions to enter the line than others.

For instance, a position in which the tubing exits the sampling connector at an angle of 45° (position D in Figure 3) to the ceiling often is good. Keeping the sampling adapter vertical (position E) may be another option.

### Extubated Patients

In extubated patients, nasal oxygen prongs with a CO<sub>2</sub> sampling port may be used. We have found that the CO<sub>2</sub> signal generally is good with the “split prongs” that deliver oxygen to one nostril and sample CO<sub>2</sub> from the other nostril (e.g., End Tidal CO<sub>2</sub> Divided Sampling Cannulas, Salter Labs, Carlsbad, CA). Alternatively, nasal prongs that deliver oxygen to, and sample CO<sub>2</sub> from, both nostrils can be used.

In patients who are breathing oxygen through a face mask, CO<sub>2</sub>-sampling nasal prongs can be placed in the usual position on the patient’s nose, under the mask. Oxygen is not delivered through these nasal prongs; just the CO<sub>2</sub> is sampled. A much better capnogram will be obtained than sampling above the face mask or with a plastic IV catheter attached to the mask.<sup>45,46</sup>

### Airway Pressure and Flow Measurements

Theoretically, more accurate measurements may be obtained via devices that measure at the connector of the endotracheal tube rather than at the machine end of the breathing circuit. Otherwise, the additional volume in the breathing circuit will alter the readings because it also is compressed during mechanical ventilation.<sup>47,48</sup>

In clinical practice, the site of measurement may make little difference, however. Many modern ventilators and anesthesia machines compensate for the circuit compliance and can obtain accurate volumes from a more distal measurement (i.e., away from the endotracheal tube).<sup>49</sup>

### Invasive Blood Pressures

Pressure transducers often will have a drift of the electrical signals after they have been connected to the monitor and “warmed up” for 10–15 minutes. Pressure transducers should always be rezeroed 10–15 minutes after initial electrical connection.<sup>50</sup>

Pressure transducers should be zeroed to the correct level on the patient's body. Normally, this level is the most superior point of the right atrium. In an adult, this point is typically 5 cm (approximately 2 inches) below (posterior to) the left sternal border at the fourth intercostal space (below the location of the V2 ECG lead).<sup>51</sup>

A length of IV tubing (perhaps two or three lengths of 3-foot IV extension tubing, attached together), open at both ends, with one end at the correct zero level on the patient and the other end on an IV pole with the pressure transducers, can be used as a siphon by filling it with saline and letting the liquid decrease to the patient's zero level. The transducers then can be opened to air at this zero level several feet away (e.g., attached to a pole for IV fluids). If the transducer open-to-air point is not at the proper heart level, the transducer will measure incorrectly according to its offset (Figure 4).

If the monitor has a selection for spontaneous versus automatic ventilation, be sure that it is set correctly. The monitor uses this setting to read the pressure at end expiration (which is the correct time that it should be read).

If the patient is on an assist mode, such as synchronized intermittent mandatory ventilation or pressure support ventilation, choose automatic mode. If the patient is breathing spontaneously most of the time with a backup mechanical mode, choose spontaneous mode.

## Temperature

Choose the site of temperature measurement carefully.

Bladder temperatures are accurate when the patient has good urine flow and may be less accurate with oliguria.<sup>52-54</sup>

Esophageal and nasal temperatures may be affected by warmed or cool gases in the airway (endotracheal tube, supralaryngeal airway, or face mask) and by air or fluid flow through a nasogastric or orogastric tube.

Intravascular temperatures (e.g., Swan-Ganz catheter) may be affected by warmed, room temperature, or cold fluids that are infused.<sup>55</sup>

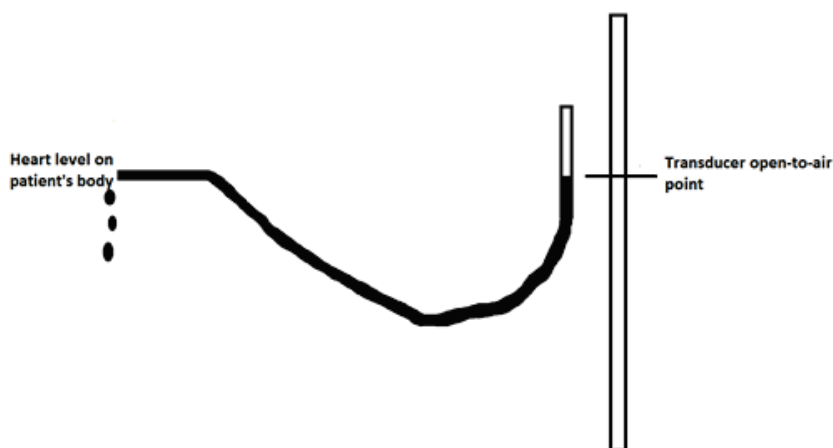
Skin and axillary temperatures may be affected by ambient temperature, including the use of water mattresses, air mattresses, and warming blankets.<sup>56</sup>

## Conclusion

These principles are simple to follow and will result in good signals with fewer artifacts, thereby resulting in signals that are less likely to produce false alarms. ■

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**Figure 4.** A suitable length of intravenous tubing (such as two or three intravenous extension sets, connected together) is attached to an IV pole at a height above the patient. The other end of the tubing is attached to or near the patient, so that the end is horizontal and at the height of the superior-most point of the right atrium. (See text.) Cloth or gauze pads should be placed under the patient end of the tubing, but not touching it. The tubing is then filled from the end at the IV pole, and allowed to drain out the patient end. At this point, the level of the tubing on the IV pole will be the same as the level of the superior-most point of the right atrium. This is the correct point for the open-to-air point of the pressure transducer.

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