Static Electricity and Grounding in Hyperbaric Chambers (2021)

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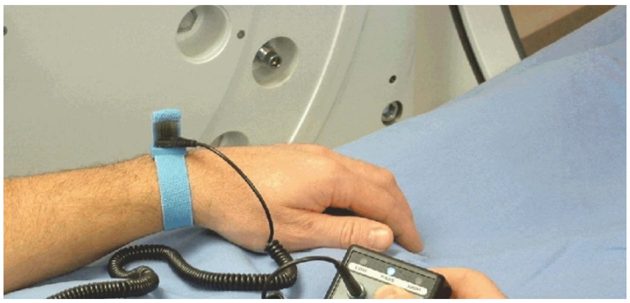


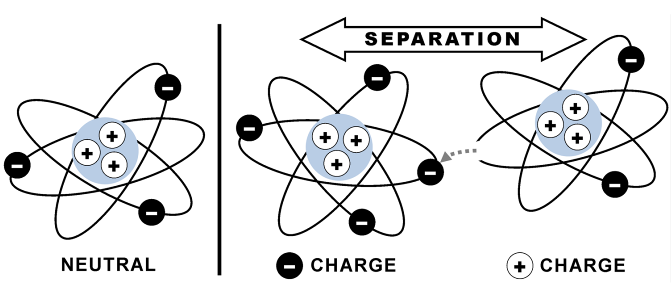
OBJECTIVES

On completion of this activity, the reader should be able to:

1. Explain accumulation of static charge.
2. Explain the role of humidity and grounding in static control.
3. Identify conductive and insulating materials on a hyperbaric chamber.
4. Explain the function of a multimeter.
5. Explain the function of a wrist strap tester.

STATIC ELECTRICITY BASICS

Static electricity is an imbalance of electric charges within or on the surface of a material (i.e. something made of matter, not necessarily a fabric). A static electric charge can be created whenever two materials contact and separate, and at least one of the materials has a high resistance to electric current. Materials are made of atoms that are normally electrically neutral because they contain equal numbers of protons (positively charged) and electrons (negatively charged). When two materials are in contact, electrons may move from one material to the other, which leaves a negative charge on one material and an equal positive charge on the other. When the materials are separated they retain this charge imbalance.



Friction of materials can cause a charge imbalance. Examples are: fabrics rubbing together, skin rubbing against fabric, shoes moving across carpet, or the friction of something moving through air. Some materials tend to generate more static electricity than others. This is one reason that silk, wool, and synthetic textiles are prohibited from hyperbaric chambers by the National Fire Protection Association (NFPA). However, static electricity can occur with any textile, including cotton.

An imbalance of charge will always try to neutralize, but needs a pathway to do so - either a conductive pathway to earth or close proximity to a material with an excess charge of opposite polarity (positive or negative). If there is no pathway, the electrical charge will build on the surface of a material. When the charge builds high enough, a spark will jump to earth (or to another material).

Conductors and insulators are opposites. Charge flows across conductive materials but will not flow across insulated materials. If charge is created on the surface of a conductive material, the charge is distributed across the surface of the material. Conversely, if charge is created on the surface of an insulated material, it will concentrate in that area. A perfect conductor will offer no resistance to the flow of charge. A perfect insulator will offer infinite resistance to the flow of charge. Most materials are somewhere between a perfect conductor and a perfect insulator. To determine where a material falls on this spectrum, we measure the material's resistance to electrical flow. Less resistance means the material is a good conductor. More resistance means the material is a poor conductor. Resistance is measured in Ohms, and indicated by the Greek letter omega (Ω). A perfect conductor generates zero Ohms ($0\ \Omega$) of resistance. A perfect insulator generates infinite Ohms ($\infty\ \Omega$) of resistance.

To summarize, all materials have the potential to generate static electricity. The extent to which the static charge will dissipate is a function of the conductivity of the material.

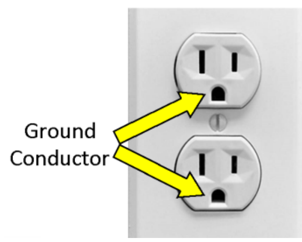
CONTROLLING STATIC CHARGE

When attempting to reduce or eliminate static electricity, there are two considerations. One is to select materials that generate less static charge. The second consideration is to provide static charge a pathway to earth by using conductive materials.

Humidity provides a flow path for static charge because water is conductive. At a relative humidity of 65% or greater, a material should not accumulate static charge. The lower the relative humidity, the more static charge can accumulate. Humidity levels in hyperbaric chambers vary greatly depending on several factors.

- The source of pressurization gas: Gas from a liquid oxygen supply or from a high-pressure cylinder is completely dry. Gas from an air compressor has varying amounts of moisture, depending on humidity levels around the compressor air intake and whether or not there is an air dryer in the system.
- The number and size of chamber occupants: More occupants produce more humidity inside a chamber. When chamber occupants are larger, they take up more volume thereby reducing the gas volume in the chamber. When gas volumes are smaller, humidity produced by the occupant(s) will more rapidly increase the humidity level in the chamber.
- The amount of chamber ventilation: When the pressurization gas supply is relatively dry, ventilation will reduce the humidity produced by chamber occupants. Higher ventilation levels will remove more humidity.

In general, high humidity in a chamber means less static accumulation, and low humidity in a chamber means more static accumulation. However, very humid environments are uncomfortable and most chamber mechanical components (i.e. pneumatic equipment) should be kept dry. Because of these issues and the other variables involved, humidity is generally not a reliable way to control static electricity in a hyperbaric chamber.



“Grounding” is the term used to describe the process of electrically connecting something to earth. This is accomplished by physical contact with a conductive material that has electrical continuity to earth. In buildings, the third hole on an electrical outlet is the ground conductor. Ideally, all ground conductors in a building are connected to a single earth ground. A hyperbaric chamber should be connected to the same earth ground. If the building ground system is unreliable, a separate earth ground for the chamber might be used. Regardless, grounding of the hyperbaric chamber is important. This is the most reliable way to eliminate static charge.

NFPA 99: Health Care Facilities Code has specific requirements for grounding in hyperbaric facilities:

- The chamber must be grounded with no more than one Ohm (1 Ω) of resistance.
- Any furniture installed in the chamber must be grounded. Conductive devices on furniture must be periodically inspected to ensure they have not lost conductive properties. (Although *NFPA 99* does not specifically address the patient tray in a monoplace chamber, it would be prudent to apply this rule to the tray.)
- When the oxygen percentage inside the chamber is more than 23.5%, the occupant(s) must be grounded to the chamber with a high-resistance conductive pathway. (*NFPA 99* uses the term “high-impedance conductive pathway”. For the purpose of this discussion, impedance and resistance have the same meaning.)

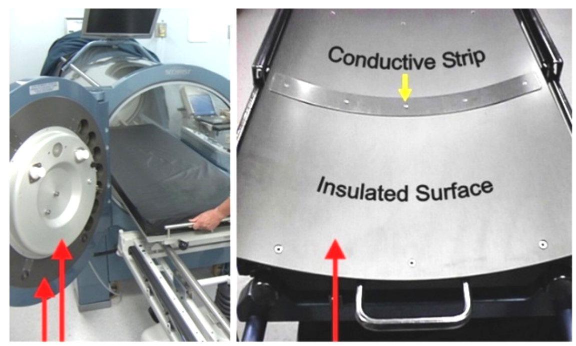
> **Why use a <u>high-resistance</u> conductive pathway?**
> *Resistance is there to prevent injury from electric shock. A high-resistance pathway allows static charge to dissipate, but prevents a large electrical current from going through the pathway. This protects the grounded person from injury. By design, the inside of a monoplace chamber should not have enough electrical energy to cause this type of injury. However, a high-resistance pathway is standard practice in the personnel grounding industry.*


Wrist Strap

The grounding of occupants in a hyperbaric chamber is accomplished with a “wrist strap”. The wrist strap (either metal or elastic wrist band) and its connecting cord (usually a coiled wire) are a high-resistance conductive pathway. The connecting cord includes a one million Ohms (1 MΩ) resistor. Because monoplace chambers are typically filled with oxygen, use of a wrist strap is common practice in monoplace chambers; but is rarely (if ever) done in multiplace chambers.

CONDUCTIVE MATERIALS

The aluminum and steel materials used to build most hyperbaric chambers are electrical conductors. Some aluminum materials have been anodized to harden the surface. Anodizing aluminum turns the surface of an otherwise highly conductive material into an insulator; but the core of the aluminum is still conductive. Steel surfaces are painted to protect against corrosion. The paint on a steel surface is typically an insulator (unless a special conductive paint finish is used); but the steel underneath is still conductive. When fasteners (e.g. bolts, screws, rivets) penetrate anodized aluminum or painted steel, they contact the core of the material, making the fastener a conductive point even though the anodized or painted surface around the fastener is not conductive.



Anodized Aluminum Surfaces

Human skin is somewhat conductive. The resistance across different people’s skin can range from several thousand Ohms to several million Ohms. When a wrist strap is used, it relies on conductivity of the skin to flow the charge from skin to wristband, to the connecting cord, to the chamber, to the building ground system, then to earth.

The plastic/vinyl covering of pillows and mattresses may or may not be conductive. Some hyperbaric chambers employ a conductive vinyl material, but most do not. The acrylic windows on all hyperbaric chambers are insulators as are the gaskets that seal around these acrylic components.

The conductive pathways in a hyperbaric chamber should be tested periodically. The frequency of this test will vary, depending on the likelihood of losing conductive properties. Conductive properties can be lost by a variety of factors, including physical disconnection, damage to conductive wires, and interference by insulating materials (e.g. dirt, oxidation). Moving parts in the conductive pathway increase the likelihood of physical disconnection and interference by insulating materials. The metal parts of a chamber should be grounded to earth (preferably through building ground system). This continuity is unlikely to change unless the chamber is moved or the ground wire is disconnected. However, furniture inside the chamber may lose a conductive path if connections become loose or if contact points become insulated by dirt, oxidation, or other materials. Where there are moving parts, such as door hinges, the continuity can be lost over time. Continuity can also be lost where the patient tray (in a monoplace chamber) has moving parts, such as wheels or a movable back rest. The connecting cord on the patient wrist strap can be broken at any time by normal wear and tear.

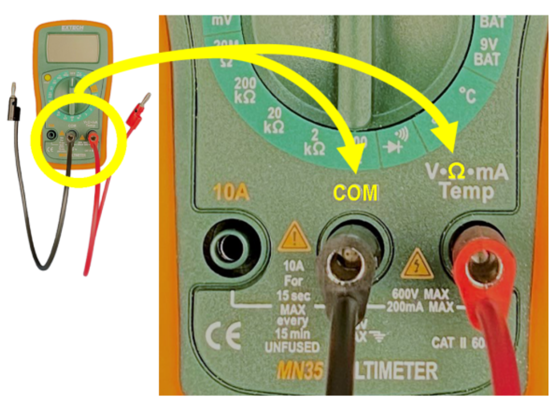
A multimeter can be used to measure the continuity of all these potential problem areas. A multimeter measures the amount of resistance from one point to another. When a wrist strap is used, the continuity of the circuit created by the patient's skin, wrist band, and connecting cord can be tested with a multimeter, or a special instrument designed for more convenient testing of wrist straps (i.e. wrist strap tester). A wrist strap tester does not measure the exact resistance. It tries to identify that the resistance is within a particular range. It will indicate "pass" when the resistance measures between eight hundred thousand Ohms (800 kΩ, 0.8 MΩ) and ten million Ohms (10 MΩ). This range allows for the one million Ohms (1 MΩ) resistor in the connecting cord and additional resistance from the patient's skin. The wrist strap tester will indicate "fail" when the resistance measured is less than eight hundred thousand Ohms (800 kΩ, 0.8 MΩ) or greater than ten million Ohms (10 MΩ). Static charge will flow against resistance of more than ten million Ohms (10 MΩ); but to know precisely how much resistance is present, one would need a multimeter rather than a wrist strap tester.

Wrist Strap Tester

The remaining contact points in a ground path should be tested periodically. The testing frequency and ground test points vary with make and model of hyperbaric chamber; but should be based on the likelihood of losing the conductive pathway from disconnection, interference from insulators, and deterioration of conductive properties. Consult your chamber manufacturer for ground testing points and the recommended frequency of testing.

ABOUT MULTIMETERS

If you purchase a multimeter, select one that is able to measure resistance up to <u>at least</u> 20 million Ohms (20 MΩ). When using any multimeter to measure resistance, the two test leads should be plugged into the multimeter ports labeled COM and Ω. The color of the two test leads does not matter.



With a standard multimeter, there are multiple settings for measuring resistance; and you must select the range of resistance to be measured, based on the expected results. When the resistance between test points is expected to be low (i.e. close to zero), select the lowest resistance setting on the multimeter. When the resistance between test points is expected to be high (i.e. at least one million Ohms), select the highest resistance setting on the multimeter.


Standard Multimeter Set to Lowest Resistance (200 Ω)

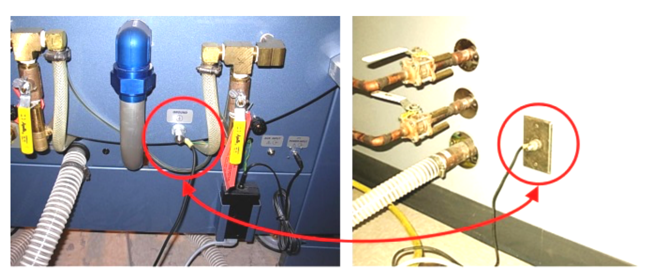

Standard Multimeter Set to Highest Resistance (20 MΩ)

An "auto-ranging" multimeter is easier to use than a standard multimeter. With an auto-ranging multimeter, there is only one setting for measuring resistance. When the multimeter test leads are applied to the test points, the auto-ranging multimeter needs a few seconds to display the measurement. In that time, it will: detect the approximate amount of resistance; automatically set the appropriate range; and display the resistance reading along with the appropriate range. The ranges are: Ohms (Ω); thousands of Ohms (kΩ); and millions of Ohms (MΩ).

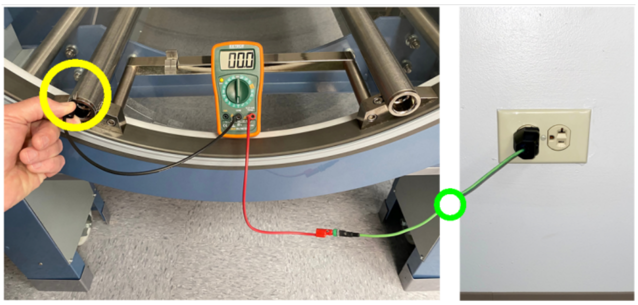
TESTING CHAMBER GROUND CONTINUITY

The same principles of ground testing apply to both monoplace and multiplace chambers. However, some issues (e.g. patient grounding, wrist strap testers) are not typically encountered in multiplace chambers. In order to address all grounding issues, a monoplace chamber is used to illustrate ground testing procedures. The testing points and techniques are similar for all brands and models of monoplace chambers.

Monoplace chambers are typically grounded by means of a thick wire connecting some point on the metal shell of the chamber to a ground stud on a nearby wall. Inside the wall, the ground stud is connected to the grounding system of the building. The *NFPA 99* specification for resistance of this ground is no more than one Ohm (1 Ω).


Ground Wire Connected to Chamber
Ground Wire Connected to Ground Stud

A multimeter is needed to verify the resistance of this ground. If you touch the two test leads of the multimeter to the two ends of the chamber ground wire, you will only be testing the continuity of the ground wire itself. Although unlikely, the ground stud on the wall may not be connected inside the wall, or may have a loose connection. It would be better to test continuity of the chamber through the building ground system. If you tap into building ground (by using the grounding conductor in any electrical outlet in the room), you could touch one multimeter test lead to this point and the other multimeter test lead to any conductive point on the chamber. The rails inside the chamber are a good test point because they are part of the grounding pathway of the patient tray. If the resistance is less than one Ohm (1 Ω), there must be continuity between the chamber rail and building ground system.

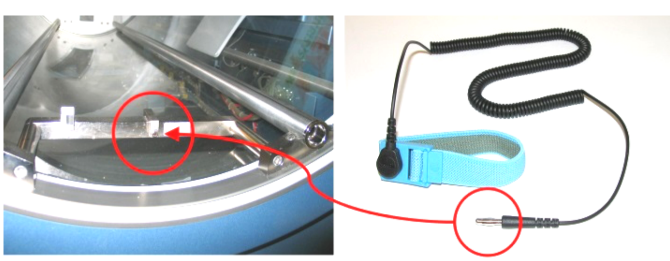


Measuring Resistance Between Chamber and Building Ground System

Be careful when tapping into the building ground system!
Do not put the multimeter test lead directly into an electrical wall outlet, you might accidentally touch one of the powered conductors, causing damage to the multimeter or injury to yourself. You should use an adapter or extension wire that only connects to the grounding contact in the electrical wall outlet.

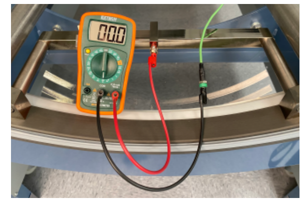
Some monoplace chambers have ground testing sockets built into the chamber, one of which has an extension wire already connected to the grounding conductor in an electrical wall outlet. Because the expected amount of resistance is zero Ohms, the multimeter should be set on the lowest resistance setting for this test. This type of test only works if the chamber is grounded through the building ground system. If the chamber has a separate earth ground, you will measure more than one Ohm (1 Ω) of resistance, and up to infinite (∞ Ω) resistance.

The same test for continuity to the building ground system should be performed at the patient grounding socket on the chamber (where the wrist strap connecting cord is plugged into the chamber).



Wrist Strap Socket on Chamber Frame

If this socket is mounted directly to the metal framework of the chamber, there should be less than one Ohm (1 Ω) of resistance between this point and the building ground system. This test assures that the wrist strap will have a ground path when connected.

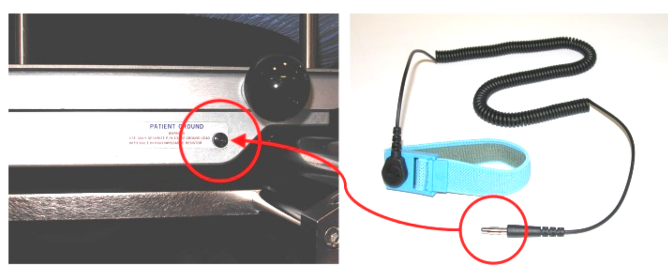


TESTING GROUND CONTINUITY THROUGH THE PATIENT TRAY

The patient tray should be grounded to prevent it from building up static charge. On the underside of the patient tray, there will be metal wheels and non-metallic wheels. The metal wheels are part of the conductive pathway of the patient tray. There will be variable resistance through the tray because of variable contact of the axles to the inside of the metal wheels and variable contact of the metal wheels to the chamber rails. The amount of weight on the tray will change the resistance. More weight will reduce resistance by pressing the wheels tighter against the axles and the chamber rails. If the tray is made up of multiple parts bolted together, the bolts can become loose and increase resistance through the frame of the tray. *NFPA 99* does not have a specification for resistance through the patient tray. However, *NFPA 77: Recommended Practice on Static Electricity* discusses the desired limits of resistance for grounding of conductive equipment. It recommends a resistance of one million Ohms (1 MΩ) or less.

The test is performed by loading the tray into the chamber, then touching one multimeter test lead to a conductive point on the frame of the tray and the other test lead to the building ground system (or the chamber rail). When performing the patient tray test, the expected amount of resistance is unknown. Start with the lowest resistance setting on the multimeter (200 Ω on the meter shown above). If the actual resistance is less than 200 Ω, the meter will display the reading. If the actual resistance is more than 200 Ω, you will have to select a higher resistance setting on the meter and test again. You may have to try multiple settings before you can see the reading. If the resistance through the patient tray exceed on million Ohms (1 MΩ), one or more of the following should be cleaned: chamber rails, patient tray wheels, axles inside the patient tray wheels. Most lubricants are insulators and should not be used on chamber rails or patient tray wheels. The axles on most patient tray wheels are not meant to be lubricated, if the axles are meant to be lubricated, the lubricant must be both conductive and oxygen compatible.

When the tray is part of the patient ground path (i.e. the wrist strap socket is on the patient tray), it should be tested frequently.



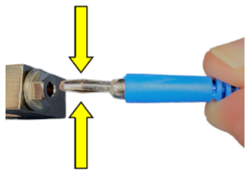
Wrist Strap Socket on Chamber Bed

The goal in this case is to ensure the tray does not interfere with the patient ground path (i.e. resistance does not exceed one million Ohms). The test is performed by loading the tray into the chamber, then touching one multimeter test lead to the wrist strap socket and the other test lead to the building ground system (or to the chamber rail). The expected amount of resistance is unknown, and should be addressed as described above.

TESTING PATIENT GROUND CONTINUITY

Starting with the 2018 edition, *NFPA 99* requires the patient ground in monoplace chambers to be verified prior to each treatment.

- The resistance of human skin is variable.
- Dryness of the skin and tightness of the wrist band will alter resistance. For the same patient, these could change day to day.
- The connecting cord can be broken by rolling over it with the patient tray, by closing the chamber door on it, or by normal wear and tear (usually near one of the two ends). This could occur at any time during the day.
- The banana plug at the end of the connecting cord can become compressed over time, causing a loose connection (and higher resistance) when it is plugged into the chamber patient ground socket or the wrist strap tester socket.



The test is performed by: tightening the wrist band on the patient; connecting the snap end of the connecting cord to the wrist band; touching one multimeter test lead to the banana plug end of the connecting cord; and touching and the other multimeter test lead to the patient's skin. The reading will be variable; but should be at least one million Ohms (1 MΩ) because of the resistor in the wrist strap connecting cord. Because the expected resistance is at least on million Ohms (1 MΩ), the multimeter should be set on the highest resistance setting for this test. *NFPA 77* discusses the desired limits of resistance for personnel grounding devices. It recommends a minimum resistance of one million Ohms (1 MΩ), and a maximum resistance of one hundred million Ohms (100 MΩ).

Multimeter Test for Skin/Wire/ Wrist Strap Resistance

Wrist Strap Tester for Skin/ Wire/Wrist Strap Resistance

A simpler way to perform this test is to use a wrist strap tester. The same test is performed, except the wrist strap tester takes the place of the multimeter. The banana plug end of the connecting cord is plugged into the wrist strap tester, and the patient holds down a conductive button with his/her thumb. The tester will indicate "pass" if the resistance of the circuit is between eight hundred thousand Ohms (800 kΩ, 0.8 MΩ) and ten million Ohms (10 MΩ). The tester will indicate "fail/high" if the resistance is higher than ten million Ohms (10 MΩ). Although the wrist strap tester is simpler than the multimeter test, "fail/high" is not conclusive. The patient can have up to one hundred million Ohms (100 MΩ) of resistance, but the wrist strap tester only measures up to ten million Ohms (10 MΩ). You would need a multimeter to be able to measure resistance higher than ten million Ohms (10 MΩ).

TROUBLESHOOTING A MULTIMETER

When a multimeter is set to measure resistance, it will indicate the amount of resistance that exists between the two test leads. When the two test leads are not touching anything, the multimeter should measure infinite resistance (or some other symbol indicating "open circuit"). When the two test leads are touching each other, the resistance should measure zero (or very close to zero). If it does not, or if the reading will not remain steady, one of the following may cause the problem:

- One or more of the test lead tips is dirty. You may need to gently abrade the metal tips to clean them.
- One or more of the test lead tips has a loose connection. The ends of some test leads are banana plugs (just like the wrist strap connecting cord). These plugs can become compressed over time making a loose connection.
- The battery(ies) in the multimeter are weak and need replacement.
- The wire inside one of the test leads is broken or partially broken.
- The multimeter is defective.

Each time you turn on a multimeter to measure resistance, you should first connect the test leads together to make sure the meter measures zero resistance (or very close to zero). This will validate that the meter seems to be working properly.

Standard Meter Set to Lowest Resistance Setting (200Ω)

Auto-ranging Meter Set to Measure Resistance (Ω)

TROUBLESHOOTING A WRIST STRAP TESTER

When using a wrist strap tester on a hyperbaric patient, "pass" and "fail/high" are expected test outcomes. "Fail/low" is unexpected. "Fail/low" indicates the resistance is less than eight hundred thousand Ohms (800 kΩ, 0.8 MΩ). The one million Ohms (1 MΩ) resistor in the connecting cord of the wrist strap should prevent you from seeing this outcome. If the wrist strap tester indicates "fail/low", it is caused by one of the following:

- The connecting cord in the wrist strap does not have a resistor. This can be verified by measuring the resistance from one end of the connecting cord to the other end with a multimeter. If the multimeter test shows approximately one million Ohms (1 MΩ), the resistor is present.
- The battery(ies) in the wrist strap tester are weak and need replacement.
- The wrist strap tester is defective.

"Fail/high" indicates the resistance is more than ten million Ohms (10 MΩ). This can be verified by replacing the wrist strap tester with a multimeter and measuring the actual amount of resistance. When you test a patient with both the wrist strap tester and multimeter, make sure the wrist band contact with the skin is unchanged for both tests and the skin contact point (e.g. thumb, finger) is the same for both devices. If the multimeter test disagrees with the wrist strap tester (i.e. the wrist strap tester reading is "fail/high" but the multimeter measures less than 10 MΩ of resistance), it is caused by one of the following:

- The battery(ies) in the wrist strap tester are weak and need replacement.
- The wrist strap tester is defective.

If the multimeter test agrees with the wrist strap tester (i.e. the multimeter measures more than 10 MΩ of resistance), it is caused by one of the following:

- The wrist band is loose and not making good contact with skin.
- The skin is dry and not making good contact with the wrist band. The entire wrist band is conductive (even fabric bands). However, the most conductive point will be the metal plate on the inside of the band, below the snap. Try rotating the wrist band to position this metal plate elsewhere on the wrist. Special lotions are also available to help improve the conductivity of dry skin.
- Hair on the arm is interfering with contact between skin and wrist band. Try rotating the wrist band to position the metal plate (mentioned above) on the inside of the wrist where there is no hair.
- The connecting cord is broken. In this case, the multimeter test would measure infinite resistance (∞ Ω). If the connecting cord is broken, the patient will not be grounded.

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