Static Electricity and Grounding in Hyperbaric Chambers

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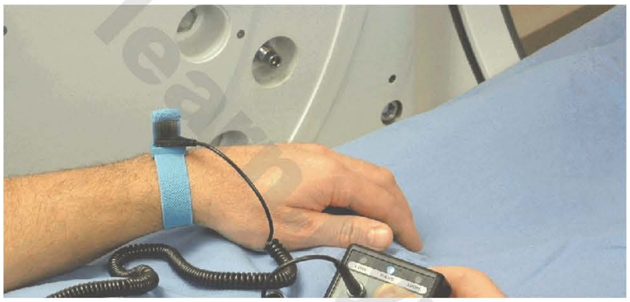


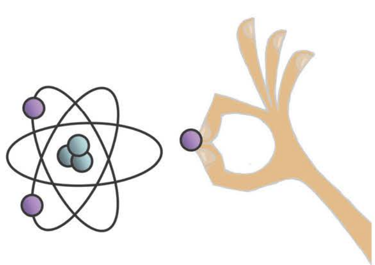
OBJECTIVES

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 electrical charge created by the accumulation of free electrons. Electrons become free when friction tears them from their atoms or when dissimilar materials contact and then separate from one another. Examples are: fabrics rubbing together, skin rubbing against fabric, shoes moving across flooring/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 generally prohibited from hyperbaric chambers. However, static electricity can occur with any textile, including cotton.



Free electrons will always try to flow to earth, but need a pathway to get there. If they do not have a pathway, the electrical charge will build on the surface of a material as free electrons accumulate. When the charge builds high enough, a spark will jump to earth (or to another material).

onductors and insulators are opposites. Free electrons flow across the surface of conductive materials but will not flow across the surface of insulated materials. If free electrons are created on the surface of a conductive material, they are distributed across the surface of the material. Conversely, if free electrons are created on the surface of an insulated material, they tend to concentrate in one area. A perfect conductor will offer no resistance to the flow of electrons. A perfect insulator will offer infinite resistance to flow of electrons. 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 resistance 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 high-pressure cylinders is completely dry. Gas from air compressors has varying amounts of moisture, depending on humidity level around the compressor air intake, high-pressure compressor versus low-pressure compressor, 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 occupants will more rapidly increase the humidity level in the chamber.
- The amount of chamber ventilation: When gas from the chamber is exhausted out and simultaneously replaced by an equal amount of gas (i.e. ventilation), the humidity produced by chamber occupants is removed in the exhaust gas. 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. Because of the 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. This is the most reliable way to eliminate static charge. "Building common ground" (i.e. every grounding wire throughout the building is tied to a single earth ground) is the standard for hospitals in the United States. It is important to know that throughout the world, the reliability of building ground systems will vary. If the building ground system is reliable, building common ground is the preferred way to ground a hyperbaric chamber (rather than the chamber having a separate 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.

The National Fire Protection Association (NFPA) code for hyperbaric facilities (NFPA 99) has specific requirements for grounding:

- 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.
- When the oxygen percentage inside the chamber is more than 23.5%, the occupant(s) must be grounded to the chamber with a high-impedance conductive pathway. (For the purpose of this discussion, "impedance" and "resistance" have the same meaning.)

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 resistance across the wrist strap is intended to be one million Ohms (1 MΩ). 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.

Why use a high-impedance conductive pathway?

The resistance is there to protect the person from electric shock. If a person is grounded with no resistance, and he/she were to come in contact with a live electrical current (perhaps from a faulty piece of equipment), the full force of that current would travel through the person's body in order to reach earth. A high-resistance pathway is sufficient to allow static charge to reach earth; but the resistance prevents a large electrical current from going through this pathway, thereby protecting the person from injury. By design, the inside of a monoplace chamber should not have enough electrical energy to cause this type of injury. However, use of a high-resistance pathway to ground people is the standard practice of the electrostatic discharge industry.

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 a conductor. Steel surfaces are painted to protect against corrosion. The paint on a steel surface is typically an insulator (unless a special conductive paint finish it used); but the steel underneath is still a conductor. When fasteners (i.e. 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 it 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 the conductivity of the patient's skin to flow electrons to the wrist band; then those electrons can flow from the wrist band, to the connecting cord, to the chamber, to earth.

The plastic/vinyl covering of pillows and mattresses may or may not be conductive. At the time of this writing, some hyperbaric chambers employ a conductive vinyl material, but most do not. The acrylics (e.g. multiplace windows, monoplace tubes) 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 measured periodically. The frequency of this test will vary, depending on how likely the conductive properties could be lost. 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 the building or directly to earth. 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 over time where the patient tray (in a monoplace chamber) has moving parts, such as wheels or a movable back rest. The connecting wire on the wrist strap used to ground a patient can be broken at any time by normal wear and tear.

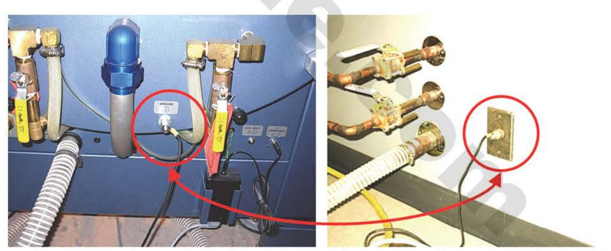
A multimeter can be used to measure the continuity of all these potential problem areas. A multimeter measures the amount of resistance from one point to another. An auto-ranging multimeter is easier to use because it has fewer settings to learn. When a wrist strap is used, the continuity of the circuit created by the patient's skin, wrist band, and coiled wire can be tested with a multimeter, or a special instrument designed for more convenient testing of wrist straps. 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 wire 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 may still 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.

Auto-ranging Multimeter Wrist Strap Tester

The remaining contact points in a ground path should be tested periodically. The testing frequency and ground testing 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.

TESTING 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.



Ground Wire Connected to Chamber Ground Wire Connected to Ground Stud

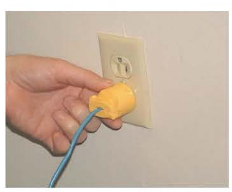
Monoplace chambers are typically grounded by means of a thick wire connecting some point on the metal shell of the chamber to a ground stud on a nearby wall. Inside the wall, the ground stud is connected to either building common ground (preferred) or to a separate earth ground. The NFPA 99 specification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

Measuring Resistance Between Chamber and Building Common Ground

A multimeter is needed to verify the resistance of this ground. If you touch the two probes of the multimeter to the two ends of the ground wire, you will only be testing the continuity of the ground wire. Although unlikely, the ground stud on the wall may not be connected to anything inside the wall. A better test would include more elements between the two probes of the multimeter. If you somehow tap into building common ground (by using the grounding contact in any electrical wall plug in the room), you could touch one multimeter probe to this point and the other multimeter probe 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 chamber bed. If the resistance is less than one Ohm (1 Ω), there must be continuity between the chamber rail and building common ground. Some newer monoplace chambers have ground testing sockets built into the chamber, one of which has an extension wire already connected to the grounding contact in an electrical wall outlet. This type of test only works if the chamber is grounded through building common ground. 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.

Be careful when tapping into building common ground!

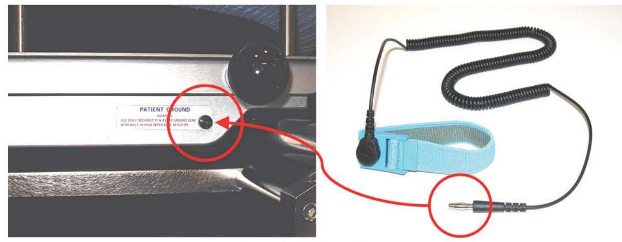
If you put one of the multimeter probes directly into an electrical wall outlet,you might accidentally touch the probe to the wrong contact, causing damage to the multimeter or inury to yourself. It is better to have an extension wire of some kind – one that only connects to the grounding contact in the electrical wall outlet.



Extension Wire with Cable Connected Only to Ground Contact

The same test for continuity to building common ground should be performed at the patient grounding point on the chamber (wrist strap socket). 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 building common ground. This test assures that the wrist strap will have a ground path when connected.

Wrist Strap Socket on Chamber Frame



Wrist Strap Socket on Chamber Bed

If the wrist strap socket is on the chamber bed, you will likely measure more than one Ohm (1 Ω) of resistance between the wrist strap socket and building common ground. The wheels on the underside of the chamber bed will have variable resistance because of variable contact of the axles with the inside of the wheels and variable contact of the wheels with the chamber rails. If the chamber bed is made up of multiple parts bolted together, the bolts can become loose and increase resistance through the frame of the bed. The goal in this case is to ensure the bed does not interfere with the patient ground path. There is no guidance on the acceptable amount of resistance through the chamber bed, because NFPA 99 does not specifically address it. However, it is logical to assume that if the wrist strap has one million Ohms (1 MΩ) of resistance by design, it would be acceptable for the bed to have as much as one million Ohms (1 MΩ) of resistance. When the bed is part of the patient ground path, it should be tested frequently. The test is performed by loading the bed into the chamber, then touching one multimeter probe to the wrist strap socket and the other probe to building common ground (or to the chamber rail).

Even when the patient is not grounded through the chamber bed, the bed itself should be grounded to prevent it from building up static charge. NFPA 99 has no specific guidance on the acceptable amount of resistance. However, the guideline *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 bed into the chamber, then touching one multimeter probe to a conductive point on the frame of the bed and the other probe to building common ground (or the chamber rail). The amount of weight on the bed will change the resistance. More weight will press the wheels tighter against the chamber rails. The same effect can be illustrated by holding the multimeter probes loosely then tightly with your fingertips.

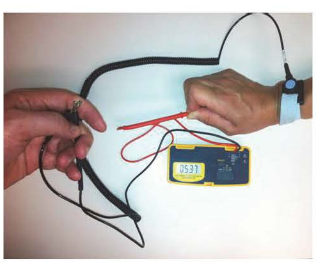

Probes Held Loosely (7.86 MΩ)


Probes Held Tightly (4.49 MΩ)

The continuity between the patient's skin and the wrist strap socket should be tested frequently. NFPA 99 does not offer any specific guidance on the frequency of this testing. However, it is logical to test the continuity of this circuit before every treatment, for the following reasons:

- 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 coiled wire can be broken by rolling over it with the chamber bed, 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 test is performed by tightening the wrist band on the patient and connecting the coiled wire to the wrist band (with the snap end of the coiled wire), then touching one multimeter probe to the other end (the banana plug end) of the coiled wire and the other multimeter probe to the patient's skin. The reading will be variable; but should be at least one million Ohms (1 MΩ) because of the resistor built into the wrist strap. 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 coiled wire 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" if the resistance is outside this range. If your chamber has built-in ground testing sockets, you can perform a modified version of this test, including more elements in the circuit.


Multimeter Test Between Banana Plug of Connecting Wire and Skin


Wrist Strap Tester Between Banana Plug of Connecting Wire and Skin

TROUBLESHOOTING A MULTIMETER

When a multimeter is set to measure resistance, it will indicate the amount of resistance that exists between the two probes. When the two probes are not touching anything, the multimeter should measure infinite resistance (or some other symbol indicating "open circuit"). When the two probes 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:

- The battery(ies) in the multimeter are weak and need replacement.
- One or both of the metal probe tips is creating resistance. Make sure the metal probe tips are clean. You may need to gently abrade the metal tips to clean them.
- The wire inside one of the test leads is faulty.


Verifying Multimeter Accuracy

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 wire 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 wire in the wrist strap does not have a resistor. This can be verified by measuring the resistance across the connecting wire with a multimeter.
- 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 devices (i.e. wrist strap tester and multimeter), make sure the wrist band contact with the skin is unchanged for both tests and the skin contact point 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 elastic 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 wire is broken. In this case, the multimeter test would measure infinite resistance (∞ Ω).

If the connecting wire is broken, the patient will not be grounded. If the wrist strap tester indicates "fail/high" for any other reason, the patient may still have a ground path. NFPA 99 does not have a standard for the limit of resistance in a high-resistance conductive pathway (i.e. the wrist strap connected to human skin). However, the *NFPA 77* guideline 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).

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