ELECTRICAL HAZARDS IN HOSPITALS

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Outline

- Some statistical facts
- How electricity works
- Human Body and Electricity
  - Skin Model
- Safety Standards
- Potential Hazards in Hospital
- Examples
- Recommendations

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Some Statistical Facts

- In 1970s, ~20,000 death/year due to electric shocks in hospitals in US hospitals
- According to 2008's report, ~98000 death/year in US hospitals due to medical errors resulting $17 to $29 billion in health care costs.
- As of Oct. 2008, Medicare (US) stopped paying for "Never Events".

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Never Events

- Unintended retention of a foreign object in a patient after surgery or other procedure
- Patient death or serious disability associated with a medication error
- **Patient death or serious disability associated with an electric shock while being cared for in a health care facility**
- Patient death or serious disability associated with a fall while being cared for in a health care facility
- Artificial insemination with the wrong donor sperm or donor egg

Source: The National Quality Forum.

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Some Incidents

- Many electrical shocks and death in hospitals in 1960-1970s that resulted in a continuous revision of the safety codes and standards since then.
- A woman (mid 60s) in Washington D.C., after a successful thyroid surgery received an electrical spark on turning off the anaesthesia machine and died 4 hours later. – Feb. 1971
- A patient in a large Michigan hospital was discovered with 3rd degree burn from ECG leads. – Dec. 1970
- About 25,000 electrocution in hospitals across US in 1970s.

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Some Recent Incidents

- Electric shock killed flue patient in hospital in China while showering in her room; July 2009
  - http://www.chinadaily.com.cn/cndy/2009-07/04/content_8377553.htm
- A patient died from an electric shock due to short circuit in a private hospital in Egypt; Jan. 2008.
  - http://www.dailystaregypt.com/article.aspx?ArticleID=11458
- A 4-year old gild died due to electrocution by a heart monitor; Dec. 1986.
  - http://www.nytimes.com/1986/12/05/us/around-the-nation-hospital-electrocution-of-child-is-investigated.html
- Several electrocution of the infants duringg apnea monitoring in 1993.
  - http://www.fda.gov/downloads/MedicalDevices/Safety/AlertsandNotices/PublicHealthNotifications/ucm063100.pdf

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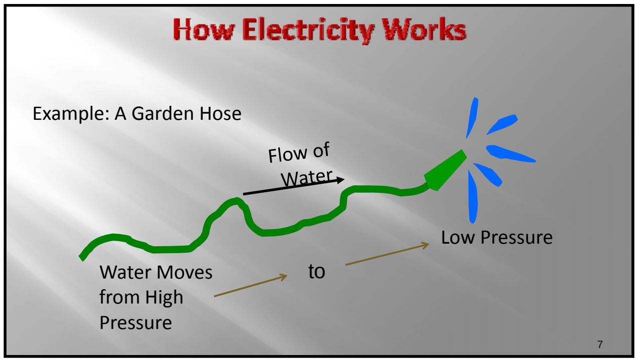
How Electricity Works
Example: A Garden Hose
Flow of Water
Low Pressure
Water Moves from High Pressure
to
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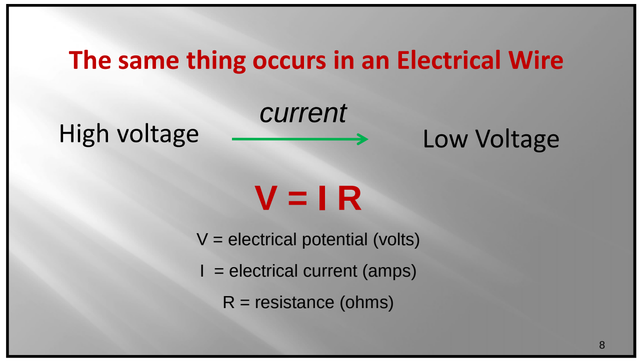
The same thing occurs in an Electrical Wire
High voltage
current
Low Voltage
V = I R
V = electrical potential (volts)
I = electrical current (amps)
R = resistance (ohms)
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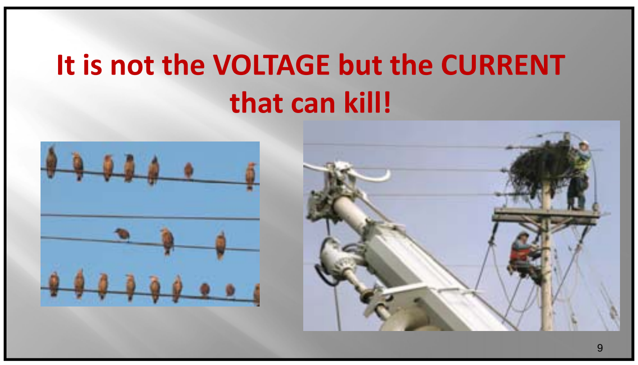
It is not the VOLTAGE but the CURRENT that can kill!
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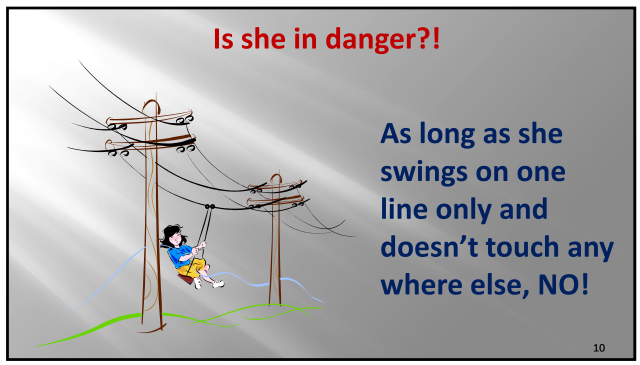
Is she in danger?!
As long as she swings on one line only and doesn't touch any where else, NO!
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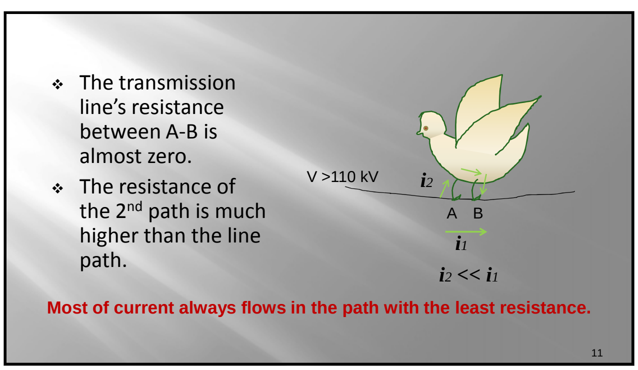
The transmission line's resistance between A-B is almost zero.
The resistance of the 2nd path is much higher than the line path.
V >110 kV
i2
A B
i1
i2 << i1
Most of current always flows in the path with the least resistance.
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Quite often the large eagles close to the power post get electrocuted and die.
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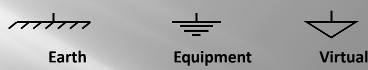
The Concept of Ground

- Symbol:



- Grounding is extremely important for both **Safety** & **Noise** in the recording/displaying
- **Earth Ground:** Absolute Zero Volt (a well with a rod of at least 8 ft in contact with the soil directly)
  - The devices with 3-wire cords are connected to Earth Ground 
- **Floating Ground:** Any reference point of the lowest voltage (can be potentially dangerous)

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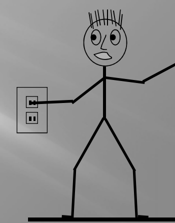
Concept of Ground

- **Is he in danger?**
- **Would it make a difference if this guy stands on one foot? Better or worse?**



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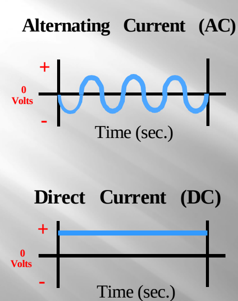

- **AC is what comes out of wall outlets.**
- **In the West, it is 60 cycles/sec (60 Hz).**
- **DC flows in one direction.**

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Does it matter if we receive an AC or DC shock?

We need to know how our skin behaves as the frequency changes

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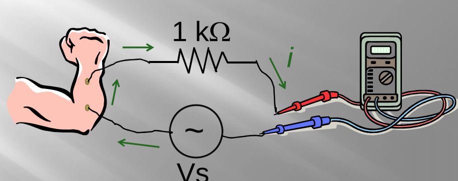
Skin Resistance Measurement



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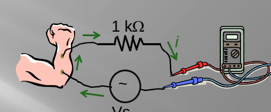
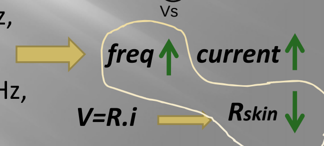
Some Measurements

- Vs= 2 V dc, i=0.9 μA
- Vs= 2 V p-p at 60 Hz, i=10.5 μA
- Vs= 2 V p-p at 1 kHz, i=75 μA
- Vs= 2 V p-p at 10 kHz, i=0.1 mA





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Since skin's resistance changes as the *freq.* changes, hence:

Skin's model cannot be not just a simple resistance

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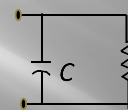
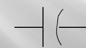
A Simple Skin *Impedance* Model

Z*skin* →





Capacitor is an element that there is a 90 deg phase shift between its voltage and current; hence its I-V relationship is frequency dependant.

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Impedance of a Capacitor: $Z_c = \frac{1}{jc\omega}$

But what we measure: $|Z_c| = \frac{1}{c\omega}$

Impedance of a Resistor: $Z_R = R$

Generalized Ohm's Law: $|V| = |Z.I|$

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Reminder

- When you connect two elements in series, the effective resistance increases; but **in parallel connection, the effective resistance decreases.**
- A capacitor shows a very high resistance at low frequency and a very low resistance at high frequencies.

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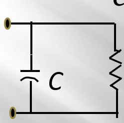
$|Z_c| = \frac{1}{c\omega}$ and $Z_{skin} = Z_c \parallel R_{skin}^{dc}$



Therefore,

freq ↑ ***Z****c* ↓ ⇨ ***Z****skin* ↓

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Skin's electrical property depends on:

- **Temperature**
  - Sweat & wet skin reduces skin's resistance significantly.
- **Frequency**
  - The higher the frequency, the lower the skin resistance
    - Don't mix this concept with skin's low-pass filtering effect on pulse penetration, as in i.e. ultrasound, etc.
- **The Voltage Amplitude**

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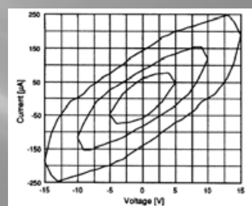
Skin Conductivity

- Skin conductivity in reality is not a linear function of either voltage nor current.

In this graph:

- V (peak)= 5, 10, and 15 Volts, f=20Hz, room temp.
- Dry skin, 1 ECG electrode on the Right forearm & Ref electrode on the Left hand.



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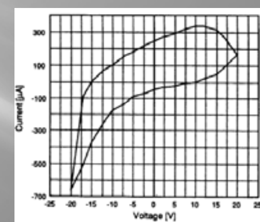
Skin Conductivity

In this graph:

- V (peak)= 20 Volts, f=20Hz, room temp., dry skin, forearm

The average breakdown voltage, 10 measurements

Subject	Forearm	Chest	Palm	Thigh
#1 male	15 V	30 V	34 V	42 V
#2 female	25 V	15 V	40 V	20 V



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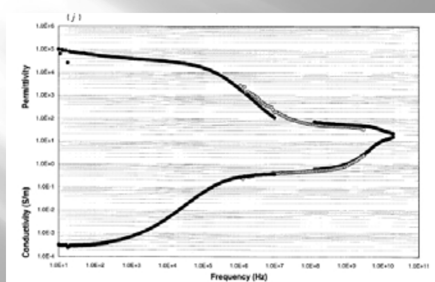
Skin Conductivity as a function of Frequency



f=0 –10 GHz

freq ↑

Zskin ↓

conductivity ↑

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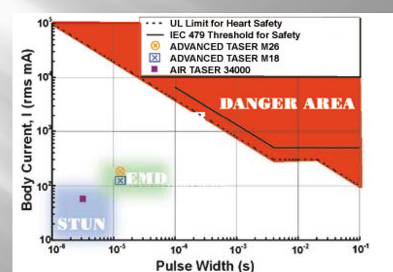
Are Tasers Safe?!



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Is he in danger?!

V socket = 170 V

R arm= R leg=100 Ω

R wet finger =150 Ω

R foot to floor=10 k Ω

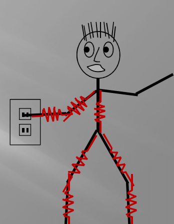
R chest=200 Ω

When standing on one foot:

$$i=\frac{v}{\sum R_i}=\frac{170}{150+100+200+100+10000}\cong 16mA$$

When standing on both feet:

$$i=\frac{v}{\sum R_i}=\frac{170}{150+100+200+50+5000}\cong 31mA$$



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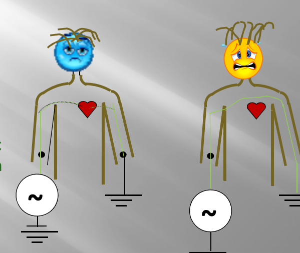
Electric Shocks

Micro Shock

The majority of the current flows through the heart.



Macro Shock

The majority of the current does NOT flow through the heart.

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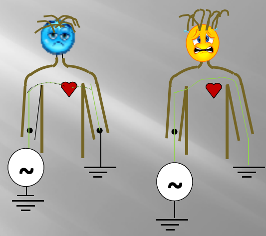
LOW VOLTAGE DOES NOT IMPLY LOW HAZARD!



An exposure of 100mA for 3 seconds can cause the same amount of damage as an exposure of 900mA for .03 seconds

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Electric Shocks

Dry Skin condition	DC (mA) Men	DC (mA) Women	AC (mA) Men	AC (mA) Women
Perception threshold	5.2	3.5	1.1	0.7
Painful shock	62	41	9	6
Let-go current			6-20	6-20
Involuntary contraction, pain, fainting			18 – 100	18 – 100
Ventricle fibrillation			**75 – 400**	**75 – 400**

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- Dry Skin resistance for AC 60 Hz current varies from 15 kΩ - 300 kΩ/cm^2.
- A wet skin's resistance can be as low as 150 Ω.
- Internal body resistance for each limb is about 200Ω, trunk = 100Ω.
- The safety limit for micro-shock = 10 μA.

Anything between 80 – 600 μA can cause fibrillation.

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Safety Limits of Current

	Chassis Leakage Current	Patient Lead Leakage
Device not in contact with patient	500 μA	NA
Device with non-isolated leads	100 μA	50 μA
Device with isolated leads	100 μA	10 μA

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Leakage Current

- It is the current that flows from the device through the grounding conductor into the Ground.
- If there is no protecting Ground wire in the unit, it can flow in any path that is provided by touching the chassis of the unit.
- Leakage Current is the main source of electric hazards in hospitals.

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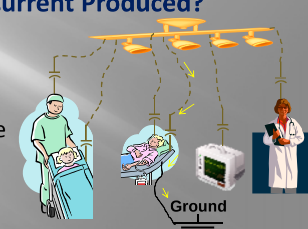
If there is no connection between the circuit board and the chassis of the device, then how is the Leakage Current Produced?

- Stray Capacitors are the culprit!
- ~2500 pF → an impedance of ~1 MΩ



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Electric Hazards

- **Faulty Ground wire** → Leakage Current will flow in any path provided by a connection to the chassis.
- **Ground Loop Current**
- Overload use of a socket → Heat, melting wire insulation, etc. (a lesser problem as fuses should protect it.)

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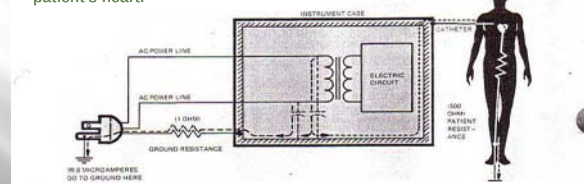
Electric Hazards in Hospital, Examples

0.1 *mA* leakage current: 99.8 mA goes to Ground; only 0.2 mA flows through patient's heart.

Normal Condition



Ground wire has only 1 Ω resistance << heart's resistance (~500 Ω)

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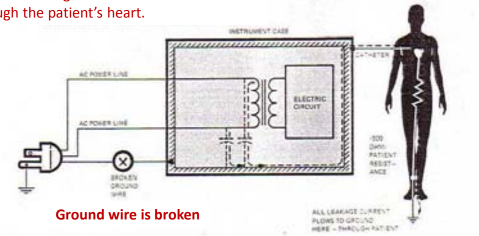
Electric Hazards in Hospital, Examples

All of the leakage current of 0.1 mA will flow through the patient's heart.



Ground wire is broken

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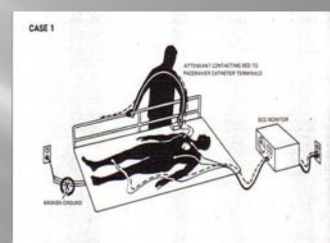
Is this patient in danger?

Ground wire of the bed is broken, patient is equipped with a transvenous pacing catheter connected to a battery operated pacemaker. Patient is also connected to an ECG monitor.



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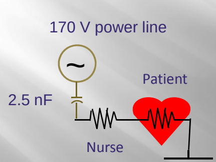
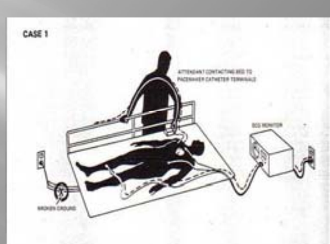
Is this patient in danger?

$$i = \frac{170V}{\sqrt{(1000000\Omega)^2 + (100500\Omega)^2}} > 0.1mA$$





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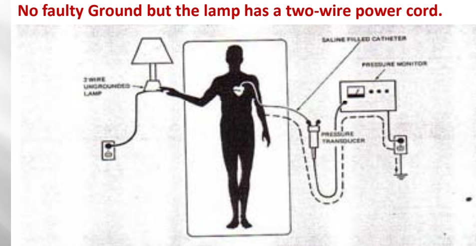
Is this patient in danger?

No faulty Ground but the lamp has a two-wire power cord.



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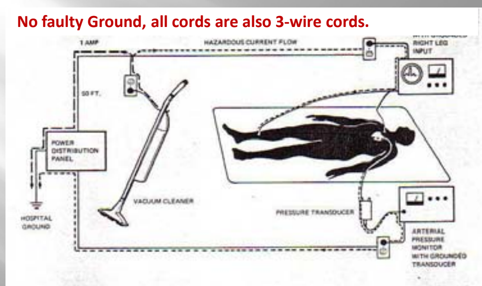
Is this patient in danger?

No faulty Ground, all cords are also 3-wire cords.



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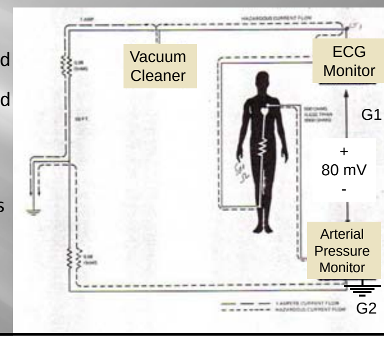
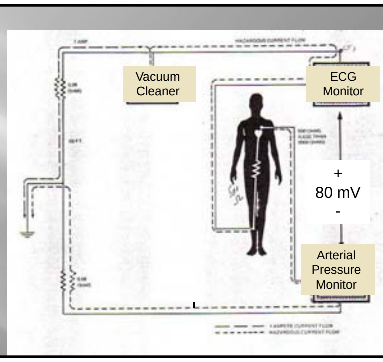
- Arterial pressure monitor and the ECG monitor are connected to 2 outlets that their grounds are connected together at a central power distribution panel many feet from the ICU area.
- The vacuum cleaner is connected into a wall outlet on the same circuit as the ECG monitor.



Is this patient in danger?

$$1A \times 0.08\Omega = 80mV$$

$$i = \frac{80mV}{500\Omega} = 160\mu A$$



Summary

- The main cause of most electric hazards are due to:
  - Faulty Ground
  - Different Grounds → Ground Loop
  - Leakage Current Flow due to Grounding problems
  - Overload of an outlet

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Recommendations

- Use of the Ground-Fault Circuit Interrupter (GFCI) does not protect the patients in ICU.
- They interrupt current if the difference between incoming and outgoing currents > 5mA

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Do Not use it for hospital devices

Power strips are approved for use only with computers and computerized equipment. They must be UL 1449 rated (surge suppressed). Power strips should be used sparingly. Care must be taken not to overload power strips.

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Do NOT use Extension Cords in Patients Care

Extension cords are approved for temporary use only. If extended use is required, hard wiring such as a new outlet should be installed. Extension cords are easily frayed, a condition which may expose bare wires. If not properly placed, extension cords may also become a trip hazard.

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Recommendations

- Use devices with 3-wire cords (having Ground wire)
- Make sure the Ground wire is not faulty.
- Use the same Ground for all devices (avoid Ground Loop).
- In cases the patient's heart is connected to a device directly, do not touch any conductive material and the patient simultaneously.

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Thank you for your attention!

Questions?