Electrical Safety in Hospitals
Safety in Hospitals

- **Laboratories**
  - Safe dealing and disposal patient specimen (blood, stool urine)
  - Safe disposal of chemicals used in testing
- **Building code**
  - Evacuation strategy incase of emergency
  - Isolation strategy incase of infection
- **Radiology**
  - Installing lead protected walls
- **Policy for safe handling needles**
- **Electrical Safety**
- **Collective effort from all hospital employees to enforce safety codes**
Scope of electrical safety

• It includes any electrically operated equipment used in
  – Public
  – General care
  – Critical care areas of the hospital
• Safety provided via
  – Power distribution
  – Equipment design
• Preventive maintenance of medical equipment
  – Frequent equipment inspections and safety checks
  – Uncovering early degradation of parts and replacements
• Education and training of medical and paramedical personnel

Electrical and Computer Engineering
Department  http://nothmany.kau.edu.sa
Physiological effect of electricity

• Electrical stimulation of excitable cells (nerves and muscles)
• Resistive heating of the tissues
• Electrochemical burns and tissue damage
• Secondary (side) effects as falling of the ladder or spilling hot oil etc.
• Need to include safety measures in the design of the device
Physiological effect of electricity

• Uncontrollable muscle contraction or unconsciousness
• Ventricular fibrillation
• Injury to tissues
  – Electrical burns
  – Chemical burns (for dc currents)
  – Muscular paralysis, injuries, pain and fatigue
  – Breaking the bones and tendons
• Secondary (side) effects as falling of the ladder or spilling hot oil etc.
Important factors and Definitions

• Threshold of Perception: Minimal current that an individual can detect.
• Let go current: Maximal current at which a person can let go voluntarily
• Factors involved:
  – Frequency of current
  – Duration of application
  – Body size
  – Point of entry
  – Gender (male or female)
Physiological effects of electricity

- Burns, injury
- Sustained myocardial contraction
- Ventricular fibrillation
- Respiratory paralysis, fatigue, pain
- Let-go current
- Threshold of perception

60 Hz 1-3 s

Electrical and Computer Engineering
Department http://notmany.kau.edu.sa
Perception thresholds and let-go currents for men and women
Let-go currents versus frequency
Fibrillation current versus shock duration
Effect of entry points in current distribution

Externally applied current spreads throughout the body

All the current applied through an intracardiac catheter flows through the heart – *cardiac shock*

Electrical and Computer Engineering
Department  http://nothmany.kau.edu.sa
Simplified electric-power distribution for 115-V, 60-Hz circuits

- Step down transformer provides 240 V at output
- High currents equipments (Autoclave, Split units, Xray ..etc) are connected across the windings of the secondary
- Other devices are connected between the hot and neutral lines (120 V)
- Different receptacles are needed to avoid overloading the devices
Receptacles connected to fuse panel
Symbolic diagram of a series circuit that may consist of many elements and conductors

- Due to magnetism and self inductance, you don’t need to touch a hotwire to get electrocuted
- Current flows from hot insulated wire through conductive surfaces through patient to ground
Patient’s electrical environment

• Electric Shock
  – Shock hazard exists between two conductors supplying either a 240-V or a 120-V appliance
  – A connection between hot conductor and any grounded surface poses a shock hazard since neutral is grounded

• Microshock can also occur if sufficient potentials can exist between exposed conductive surfaces in the patient’s environment.

• Maximal potentials permitted between any exposed conductive surfaces:
  – General-care areas: 500 mV under normal operation
  – Critical-care areas: 40 mV under normal operation

• Each receptacle must be grounded
Microshock
Direct connection to patient’s heart

• If connection is insulated all the way except at the heart, very small current can induce ventricular fibrillation
• This is called the microshock, or cardiac shock
• Current density at the point of entry can be quite high and in dogs, a current level as low as 20 µA can induce fibrillation
• Reliable human data is not available, but it is believed that currents ranging from 80 to 600 µA can cause fibrillation
• The widely accepted safety limit is 10 µA.
Safe Design: Isolated-power systems

• A good separate grounding system for each patient cannot prevent hazardous voltages in case of ground faults.

• A ground fault: Short circuit between hot and ground that injects large currents into the grounding system.

• Isolation transformer isolates both conductors (hot and neutral) from ground.

• Use a line-isolation monitor (LIM) to measure the current flowing between lines and ground in a low impedance.
Power-isolation-transformer system with a line-isolation monitor

- Internal circuits are isolated from ground
- If one line gets connected due fault to ground ➔ device works as normal supply with ground ➔ current increases in impedance ➔ alarm
- A safety limits fault currents below 5 mA – safety against macroshock hazards
- Also safety against fire since touching hot conductor to grounded surfaces cannot drive high currents needed to produce a spark.
Isolation transformer provides safety against macroshock hazards
Emergency-power systems

• An emergency system is required that automatically restores power to specified areas within 10 s after interruption of the normal power.
Un-Interrupted Power System

• Turning off power and turning back on quickly may damage some devices.

• Life support machines and devices that are sensitive to transients or take long time to power up require un-interrupted electric power

• The main power is directly connected to large capacity batteries. Once main power is off, main batteries take over the power immediately
Macroshock hazards

Protection against ventricular fibrillation is provided with:

• High resistance of dry skin
  – For dry, intact skin 15 kΩ to almost 1 MΩ
  – For wet or broken skin resistance drops down to 1%
  – Internal body resistance is about 200 Ω for the limbs and 100 Ω for the trunk

• Spatial distribution of current throughout body

• Electric equipment designed to minimize the possibility of dangerous voltages.
# Impedance per cm$^2$ of the skin tissue at 60 Hz

<table>
<thead>
<tr>
<th>Condition</th>
<th>Skin impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry skin</td>
<td>93 k$\Omega$ - cm$^2$</td>
</tr>
<tr>
<td>Electrode gel on skin</td>
<td>10.8 k$\Omega$ - cm$^2$</td>
</tr>
<tr>
<td>Penetrated skin</td>
<td>200 $\Omega$ - cm$^2$</td>
</tr>
</tbody>
</table>
Electric faults in equipment

- All electric devices are designed to minimize exposure of humans to hazardous voltages.
- Many devices have metal chassis or cabinet that can be touched dangerous.
- In ungrounded equipment, an insulation failure or shorted component between power lead and chassis may produce lethal voltages between chassis and any grounded objects.
- If a person simultaneously touches the chassis and any grounded object, a macroshock occurs.
Macroshock due to ground fault from hot line to equipment cases

- The ground conductor is not needed for operation of the equipment.
- It is not needed either for protection against macroshock until a hazardous fault develops.
- Hence, a broken ground wire or a poor connection is not detected during normal operation.
- Ground wire provides lower resistive path to ground than patient
- Continuity of the ground wire and the receptacle must be tested periodically
Common types of faults in equipment

• Failure of insulation
• Shorted components or mechanical failure that cause shorts
• Frayed power cords, plugs and receptacles due to strain, physical abuse and fatigue
• Intentional cancellation of the ground using cheater adapters
• Fluids spilled on a normally safe equipment
Common lethal electrical hazards

Cheater plug (adapter)

Electrical and Computer Engineering
Department  http://nothmany.kau.edu.sa
Faults in power cables
Microshock hazards

• Leakage currents:
  – naturally occurring current that flows between two adjacent insulated conductors that are at different potential
  – Mostly due to stray capacitance but resistive and inductive coupling to the chassis also introduce leakage currents.
  – They are usually in the order of μA.
  – They can cause microshock if care is not taken
• Conductive surfaces (limit of 40 mV)
• Conductive paths to the heart
• Microshock via ground potential differences
Assume 100 μA of leakage current from the power line to the instrument chassis. With intact ground 99.8 μA flows through the ground and the remaining flows through the patient.
Leakage current pathways (cont.)

Broken ground ➔ If the patient touches the device, then 100 μA will flow through the heart of the patient
Leakage current pathways (cont.)

Broken ground, and 100 µA flows through the heart of the patient
In opposite direction

Electrical and Computer Engineering
Department  http://nothmany.kau.edu.sa
Microshock via ground potential differences

![Diagram showing microshock via ground potential differences](image-url)
Equivalent circuit of microshock via ground potential differences

Only power system grounds are shown

Large ground-fault current raises the potential of one ground connection to the patient. The microshock current can then flow out through a catheter connected to a different ground.
Threshold of ventricular fibrillation and pump failure versus catheter area in dogs
Limits on leakage current for electrical appliance (in $\mu$A)

<table>
<thead>
<tr>
<th>Electric appliance</th>
<th>Chassis leakage</th>
<th>Patient-lead leak.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not intended to contact patients</td>
<td>100</td>
<td>NA</td>
</tr>
<tr>
<td>Not intended to contact patients, single fault</td>
<td>500</td>
<td>NA</td>
</tr>
<tr>
<td>Nonisolated patient leads</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Nonisolated patient leads with a single fault</td>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>Isolated patient leads</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Isolated patient leads with a single fault</td>
<td>50</td>
<td>300</td>
</tr>
</tbody>
</table>
Protection: Power distribution

• Grounding system
• Isolated power distribution system
• Ground-fault circuit interrupters
Grounding system

- All the receptacle grounds and conductive surfaces in the vicinity of the patient are connected to the patient-equipment ground.
- Each patient-equipment grounding point is connected to the reference room grounding point that makes a single connection to the building ground.
Wiring installation for grounded line
(beds remote from distribution panel)

Electrical and Computer Engineering
Department  http://nothmany.kau.edu.sa
Isolated power distribution system

- Protection against macroshocks
- Used with flammable anesthetics devices
Ground-fault (circuit) interrupter - GFCI

- Three wire, two pole, disconnect power if current above 6 mA
- Used also in receptacles for hair dryers, electric shavers
- Not sensitive enough to prevent micro-shock
- Should not be used with life support equipments
Ground fault interrupter
Ground-fault current versus trip time
Protection: Equipment Design

• Reliable grounding for equipment
• Reduction of leakage current
• Double-insulated equipment (ground + insulated chassis)
• Operation at low voltages (battery powered Vs < 10 V)
• Electrical Isolation through using isolated amplifiers
• Isolated heart connection
Hospital grade plugs and outlets

Figure 8-3. Hospital-grade plug.
Electrical isolation

• Isolation of the signal path
  – Optical coupling
  – Carrier type amplifier with isolation transformer
  – Capacitive coupling
  – Electromagnetic waves (telemetry)

• Isolation of the power supply
  – Battery operation
  – DC to DC converter
General model for an isolation amplifier

\[ v_o = \left( v_{\text{SIG}} \pm \frac{v_{\text{CM}}}{\text{CMRR}} \pm \frac{v_{\text{ISO}}}{\text{IMRR}} \right) \text{Gain} \]
Transformer isolation amplifier
Simplified equivalent circuit for an optical isolation

\[ v_o = v_i \frac{R_K}{R_G} \]

- CR3
- CR1
- CR2
- Isolation barrier
- RK = 1MΩ
- Input control
- Output control
Capacitively coupled isolation amplifier
Isolation in a disposable BP sensor

• Made of clear plastic so air bubbles are easily seen.
• A lever can open and close the flush valve.
• The silicon chip has a silicon diaphragm with four-resistor Wheatstone bridge diffused into it.
• A compliant silicone elastomer gel, provides electrical isolation
• It prevents electric shock to the patient and destructive currents during defibrillation from the patient to the silicon chip.
Electrical Safety Analyzer

• Commercially available devices that can perform several tests and measurements on electrical equipments
• Many tests need to be conducted on regular basis (leakage current, ground resistance, correct receptacles connection, ground to chassis resistance, leads leakage current, chassis leakage current, and more.
Three-LED receptacle tester

Tests whether wires are connected properly
Ground-pin-to-chassis resistance test

Apply 1 Amp current into ground wire and measure voltage between neutral and ground
Chassis leakage current test

To exposed conductive surface or if none, then 10 cm metal foil in contact with the exposed surface.

This connection is at service entrance or on supply side of separately derived system.

$I < 500 \mu A$ for facility-owned housekeeping and maintenance appliance.

$I > 300 \mu A$ for appliances intended for use in the patient vicinity.
Current-meter circuit to be used for measuring leakage current

The circuit has an input impedance of 1 kΩ and frequency characteristic that is flat to 1 kHz, drops at a rate of 20 dB/decade to 100 kHz, and then remains flat to 1 MHz or higher.
Test for leakage current from patient leads to ground

Electrical and Computer Engineering
Department  http://nothmany.kau.edu.sa
Test for leakage current between patient leads

This connection is at service entrance or on supply side of separately derived system

Building ground

Test circuit

Grounding contact switch (use in both OPEN and CLOSED positions)

H = hot
N = neutral (grounded)
G = grounding conductor

Patient-lead selector switch (activated as required)

Appliance power switch (closed)

Appliance

Patient-connected leads (grouped and connected as required)

Insulating surface

Current meter

$I < 50 \mu A$ for isolated patient leads with the ground open

$I < 10 \mu A$ for isolated patient leads with the ground intact
Test for ac isolation current

This connection is at service entrance or on supply side of separately derived systems.

- **H** (black) = hot
- **N** (white) = neutral (grounded)
- **G** (green) = grounding conductor

**Test circuit**

- **200 kΩ**
- **Polarity-reversing switch (use both positions)**
- **Appliance power switch (use both OFF and ON positions)**
- **Momentary switch**
- **Patient-lead selector switch (activated as required)**

**Insulating surface**

- **Patient-connected leads (check each)** (other leads left unconnected)

**Appliance**

- **Internal circuitry**

**Current meter**

**Building ground**

- **I < 50 µA** for isolated patient leads measured at normal connection between patient and patient lead.
- **I < 25 µA** for isolated patient leads at the appliance terminals.

Electrical and Computer Engineering
Department  http://nothmany.kau.edu.sa
Electrical safety

• Electrical Safety standards continuously change.
• Most commonly used standards in USA are:
  – International Society for Electrical and Electronics Engineering (IEEE)
  – Association for the Advancements of Medical Instrumentation (AAMI)
  – Saudi Commission for health specialties is in the process of developing local standards.
• Instructions to hospital staff should be given by the BMETs to nurses and other medical staff about safety. It should include:
  – Purposes and Objectives
  – Basic electricity
  – Nature of shock
  – Identification and avoidance of shock hazards
  – Reporting of hazardous situations and responsibilities
  – Pertinent publications, demonstration, conclusion and discussion