Electrical Safety

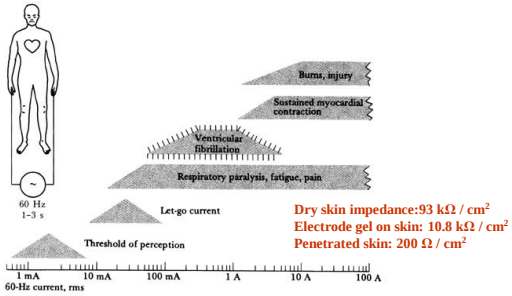
WARWICK

Dr Leandro Pecchia

Principles

- For electricity to have an effect on the human body:
  - An electrical potential difference must be present
  - The individual must be part of the electrical circuit, that is, a current must enter the body at one point and leave it at another.
- However, what causes the physiological effect is NOT voltage, but rather ***CURRENT***.
  - A high voltage (K.10^3V) applied over a large impedance (rough skin) may cause no much (any) damage
  - A low voltage applied over very small impedances (heart tissue) may cause grave consequences (ventricular fibrillation)
- The magnitude of the current is simply the applied voltage divided by the total effective impedance the current faces; skin : largest.
- Electricity can have one of three effects:
  - Electrical stimulation of excitable tissue (muscles, nerve)
  - Resistive heating of tissue
  - Electrical burns / tissue damage for direct current and high voltages

Principles



Dry skin impedance:93 kΩ / cm^2
Electrode gel on skin: 10.8 kΩ / cm^2
Penetrated skin: 200 Ω / cm^2

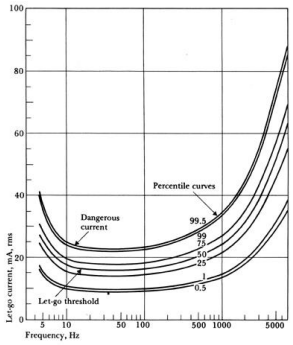
Physiological effects of electricity. Threshold or estimated mean values are given for each effect in a 70 kg human for a 1 to 3 s exposure to 60 Hz current applied via copper wires grasped by the hands.

Principles

- Threshold of perception: The minimal current that an individual can detect. For AC (with wet hands) can be as small as 0.5 mA at 60 Hz. For DC, 2 ~10 mA
- Let-go current: The maximal current at which the subject can voluntarily withdraw. 6 ~ 100 mA, at which involuntary muscle contractions, reflex withdrawals, secondary physical effects (falling, hitting head) may also occur
- Respiratory Paralysis / Pain / Fatigue At as low as 20 mA, involuntary contractions of respiratory muscles can cause asphyxiation / respiratory arrest, if the current is not interrupted. Strong involuntary contraction of other muscles can cause pain and fatigue
- Ventricular fibrillation 75 ~ 400 mA can cause heart muscles to contract uncontrollably, altering the normal propagation of the electrical activity of the heart. HR can raise up to 300 bpm, rapid, disorganized and too high to pump any meaningful amount of blood ➔ ventricular fibrillation. Normal rhythm can only return using a defibrillator
- Sustained myocardial contraction / Burns and physical injury At 1 ~6 A, the entire heart muscle contracts and heart stops beating. This will not cause irreversible tissue damage, however, as normal rhythm will return once the current is removed. At or after 10A, however, burns can occur, particularly at points of entry and exit.

Let-go current vs frequency

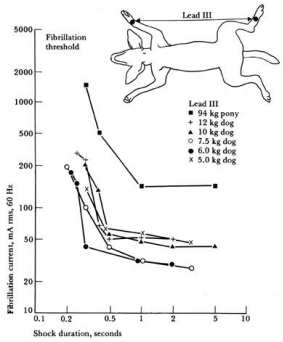
- Frequency
  - Note that the minimal let-go current happens at the precise frequency of commercial power-line, 50-60Hz.
  - Let-go current rises below 10 Hz and above several hundred Hz.



Let-go current versus frequency
Percentile values indicate variability of let-go current among individuals. Let-go currents for women are about two-thirds the values for men.

Fibrillation vs shock duration

- Duration
  - The longer the duration, the smaller the current at which ventricular fibrillation occurs
  - Shock must occur long enough to coincide with the most vulnerable period occurring during the T wave.
- Weight
  - Fibrillation threshold increases with body weight (from 50mA for 6kg dogs to 130 mA for 24 kg dogs.

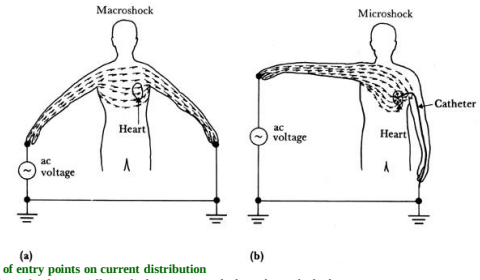


Fibrillation current versus shock duration.
Thresholds for ventricular fibrillation in animals for 60 Hz AC current. Duration of current (0.2 to 5 s) and weight of animal body were varied.

Current point of entry

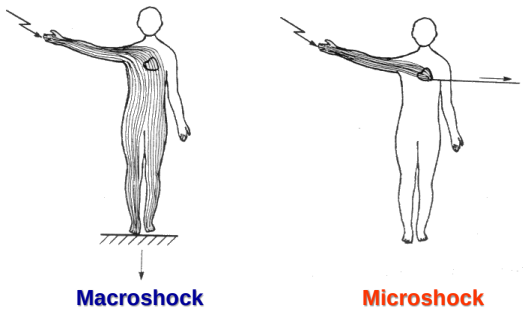
- The magnitude of the current required to fibrillate the heart is far greater if the current is **not** applied directly to heart; externally applied current loses much of its amplitude due to current distributions. Large, externally applied currents cause ***macroshock***.
- If catheters are used, the natural protection provided by the skin (15 kΩ ~ 2 MΩ) is bypassed, greatly reducing the amount of current required to cause fibrillation. Even smallest currents (80 ~ 600 μA), causing ***microshock***, may result in fibrillation. Safety limit for microshocks is 10 μA.
- The precise point of entry, even externally is very important: If both points of entry and exit are on the same extremity, the risk of fibrillation is greatly reduced even at high currents (e.g. the current req'd for fibrillation through Lead I (LA-RA) electrodes is higher than for Leads II (LL-RA) and III (LL-LA).

Current point of entry

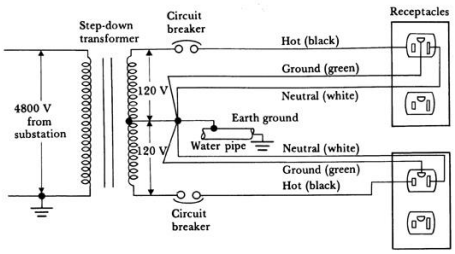


Effect of entry points on current distribution
(a) ***Macroshock***, externally applied current spreads through-out the body.
(b) ***Microshock***, all the current applied through an intracardiac catheter flows through the heart.

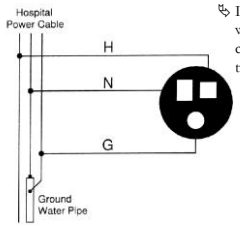
Current point of entry



Step-down transformes



Power Distribution



- If electrical devices were perfect, only two wires would be adequate (hot and return), with all power confined to these two wires. However, there are two major departures from this ideal case:
  - A fault may occur, through miswiring, component failure, etc., causing an electrical potential between an exposed surface (metal casing of the device) and a grounded surface (wet floor, metal case of another device etc.) Any person who bridges these two surfaces is subject to macroshock.

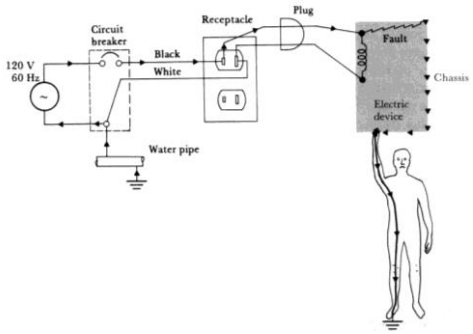
• Even if a fault does not occur, imperfect insulation or electromagnetic coupling (capacitive or inductive) may produce an electrical potential relative to the ground. A susceptible patient providing a path for this ***leakage current*** to flow to the ground is subject to microshock.

• The additional ground line provides a good line of defense! (how / why?)

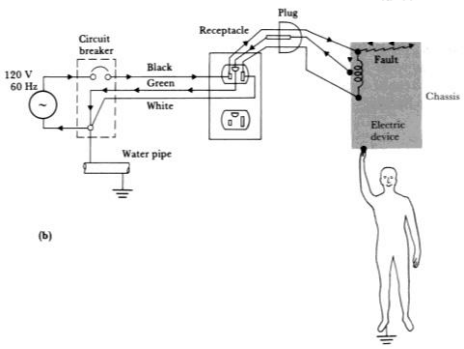
The Ground

- The additional line that is connected directly to the earth-ground provides the following:
  - In case of a fault (short circuit between hot conductor and metal casing), a large current will use the path through the ground wire (instead of the patient) and not only protect the patient, but also cause the circuit breaker to open. The ability of the grounding system to conduct high currents to ground is crucial for this to work!
  - If there is no fault, the ground wire serves to conduct the leakage current safely back to the electrical power source – again, as long as the grounding system provides a low-resistance pathway to the ground
  - Leakage current recommended by ECRI are established to prevent injury in case the grounding system fails and a patient touches an electrically active surface (10 ~ 100 μA).

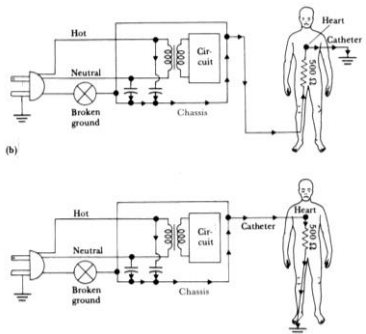
Macroshock Hazard



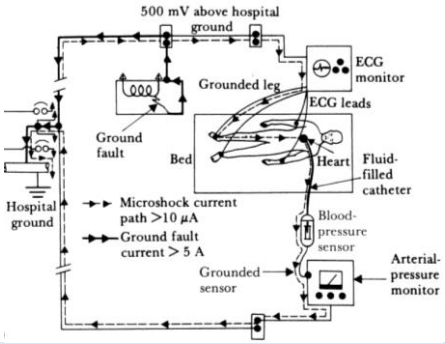
Macroshock Hazard



Microshock Hazard

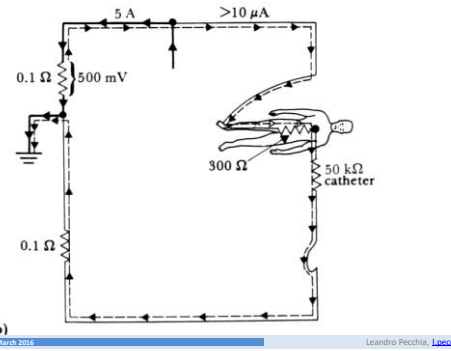


Microshock Hazard



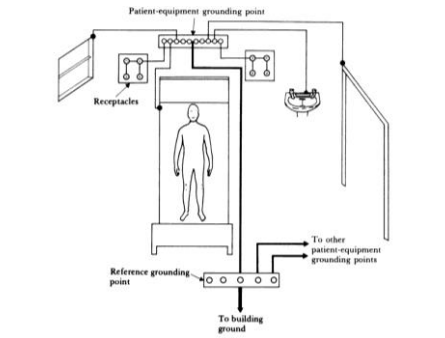
Leandro Pecchia, l.pecchia@warwick.ac.uk

Microshock Hazard



Leandro Pecchia, l.pecchia@warwick.ac.uk

Patient-Equipotent Grounding



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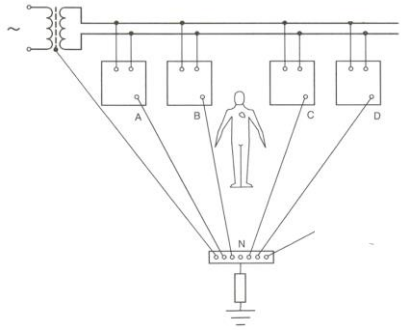

Medical device classification

- Type B – basic safety: reduced dispersion currents, no electrical contact with Patient and maybe earthed

- Type BF – more advanced safety: electrically connected to Patient but not directly to heart

- Type CF – max safety: Electrically connected to the heart of the Patient