Comparing Dry-Contact and Wet-Contact Biopotential Electrodes

By: Maraam Abulaban, Shyloh Almada, Tony Tangran Dong, Ashley Faller, Thomas Zhou

Problem Statement and Introduction

- Electrodes are very important in bioimpedance and is commonly used for measurements of biopotentials
- EMGs are generally measured by either invasive or noninvasive methods.
    - Invasive methods involve inserting an electrode needle inside or near the muscle of interest
        - Provides much more precise measurements and can provide information of individual muscle activity without “crosstalk”
        - Not suitable for long term use, preventing it from being used in everyday use devices
    - Noninvasive EMGs are measured on the surface of the skin (sEMG)
    - Many types of sEMGs exist: Wet gel-based, dry-contact and metal plate, thin-film metal plate, and noncontact metal plate through hair/clothing
    - In this project, we will be focusing on comparing Wet gel-based electrodes and dry-contact electrodes

Wet-Contact

- A conductive gel is placed between the electrode and the skin
  - Typically the conductive gels contain chloride ions
- Most commonly used is Ag/AgCl electrode
  - Taken as the gold standard given its reliability and high signal to noise ratio
- Limitations
  - Many papers have cited wet-contact electrodes as being tedious and time consuming to prepare an inconvenient.
  - Gels may cause skin irritation or allergic reactions

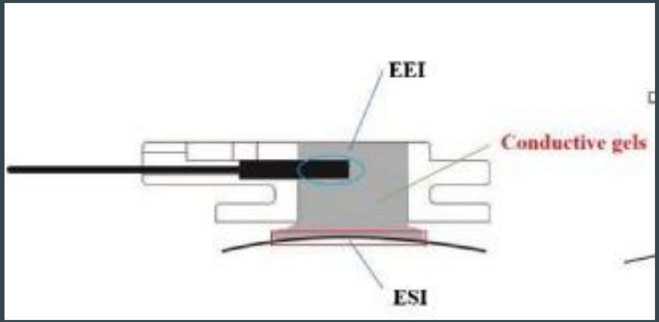


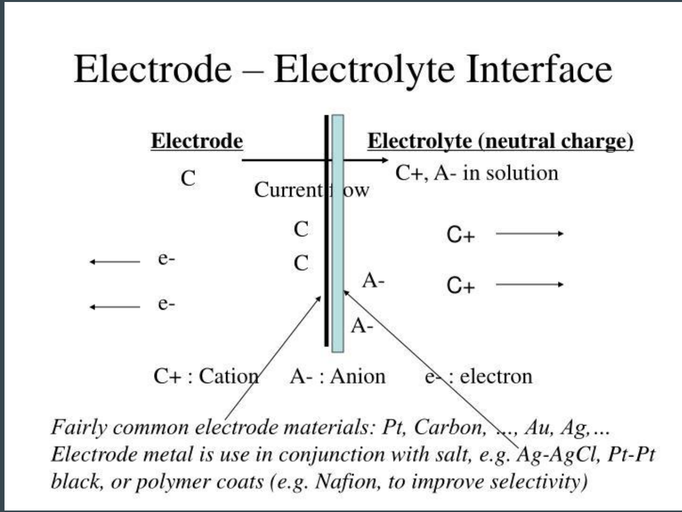
Diagram of Wet Electrode

Dry-Contact

- Transfer bioelectrical signal between the electrode and skin without any added electrolytes
- Advantages:
  - Much more comfortable for the patient
  - Longer lasting
  - Metal embedded with elastomer for increased flexibility
- Limitations:
  - Higher likelihood of motion artifacts
  - Currently limited to niche applications, such as monitoring fitness

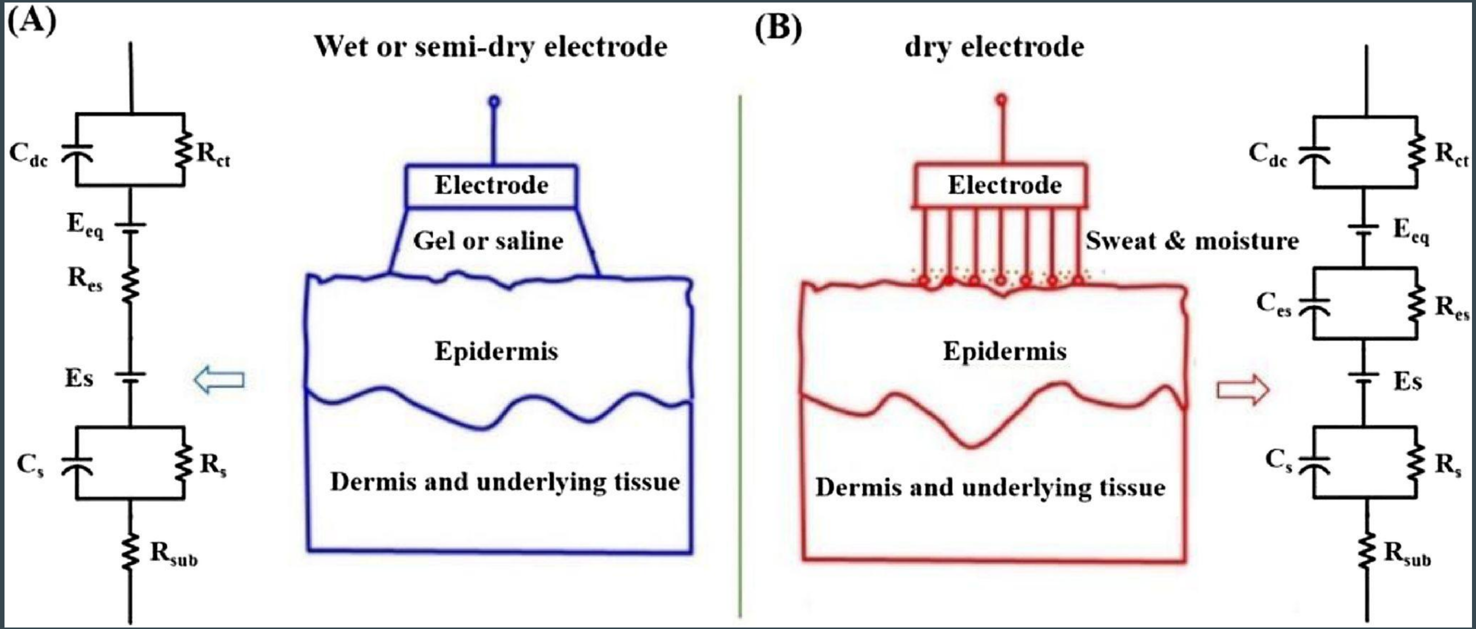
EMG Disk Electrode

Assumptions



- Polarizable and Nonpolarizable materials share the same model
- Resistance from sweat and hair follicles (R_s) and capacitance from stratum corneum (C_s) are the same for silver and platinum electrodes
- Electrodes are same size
- Steady state at electrode-electrolyte interface

Method



- At electrode-electrolyte interface the wet/semi-dry electrode differs from the dry electrode
- In wet/semi-dry electrode we use Res to represent the resistance of gel/saline solution
- In dry electrode we use a parallel combination of a capacitor and a resistor because the presence of air bubbles and sweat behave like a capacitor.

Equations

Ag/AgCl

$$Ag + Cl^{-} \rightleftharpoons AgCl + e^{-}$$

Platinum in NaCl electrolyte

$$Pt + 4Cl^{-} \rightleftharpoons [PtCl_4]^{2-} + 2e^{-}$$ [7]

Charge transfer resistor R_{ct}

According to the Tafel equation, $R_{ct} = \frac{RT}{nFi_0}$

R is gas constant, R = 8.314 $J/mol \cdot K$

T is the temperature in kelvin

n is the number of electrons involved in chemical reactions

F is the Faraday's constant, F = 96485 $C/moll$

i_0 is the exchange-current density

Half-cell potential E

According to textbook 5.6, Nernest equation

$$E = E^{0} + \frac{RT}{nF} lna_{C^{n+}}$$

E^{0} is the standard half-cell potential

n is the valence of electrode material

$a_{C^{n+}}$ is the activity of cation C^{n+}

For AgCl it is

$$E = E^{0}_{Ag} + \frac{RT}{nF} lnK_s - \frac{RT}{nF} lna_{Cl^-}$$

Double layer capacitance

	Dry electrode	Wet/Semi-dry Electrode
R_{ct}	55.8 kΩ/cm^2	1891 Ω/cm^2
C_d	10 nF	0.4157 µF

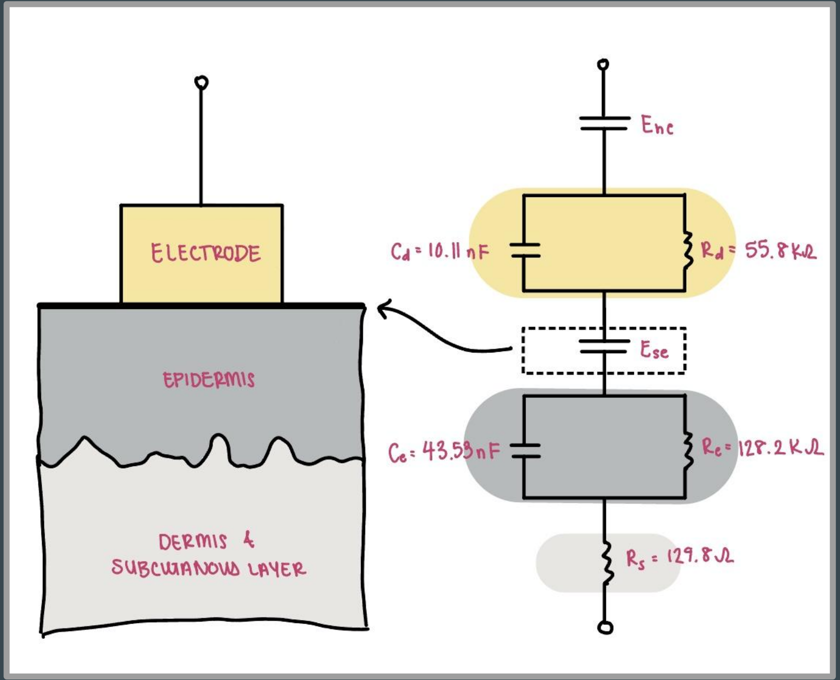
Table 2. The parameters of the dry electrode and wet/semi-dry electrode of Ag/AgCl. [2]

Metal/Ion Equilibrium Potentials	
Metal/Metal Ion	Vo [volt]
Pt/Pt^{2+}	+~1.2
Ag/Ag^{+}	+0.80

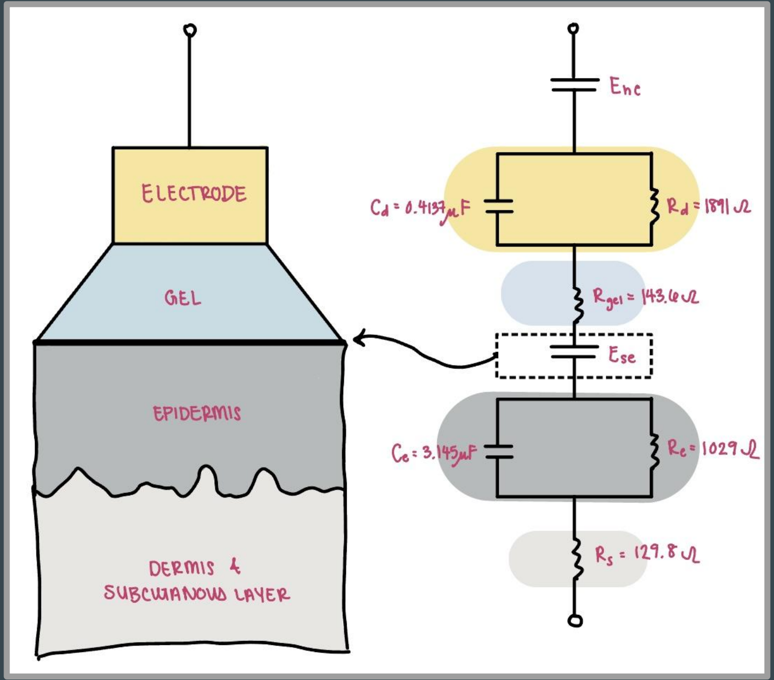
Table 1. The Equilibrium(standard) Potentials for platinum and silver ions [3]

Circuit Schematic: AgCl

Dry-Contact:

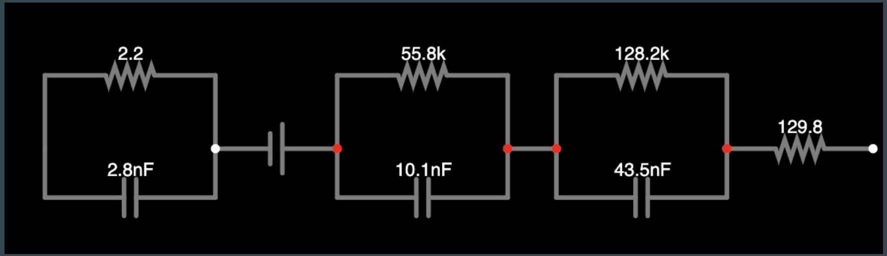


Wet-Contact:

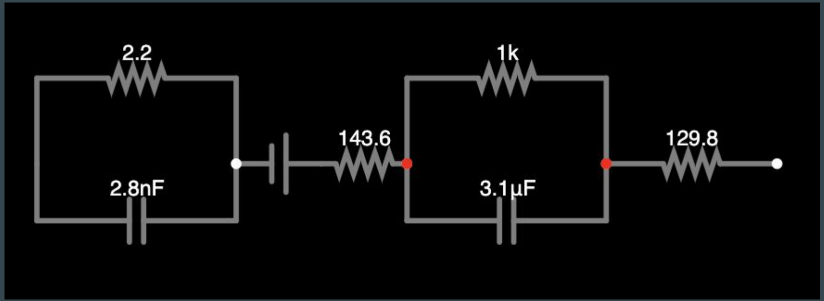


Circuit Schematic: Platinum

Dry-Contact:



Wet-Contact:



Conclusion

	Dry-Contact: *Impedance*	Wet-Contact: *Impedance*
AgCl	Z_tot = 1.85e5 Ω	Z_tot = 3.193e3 Ω
Platinum	Z_tot = 1.83e5 Ω	Z_tot = 1.27e3 Ω

Future Directions

- Can look into more electrode materials: Au, Nickel, Carbon-based electrodes, etc...
- Can explore "semi-wet electrodes"
  - Saline solution is used instead of a conductive gel
  - Acts as a design in between wet and dry electrodes
- Can research effectiveness of dry elastomer electrodes embedded metal
  - Thin film metal embedded in elastomer
  - Provides great electrical conductivity and more flexibility than the standard metal disks used in dry electrodes

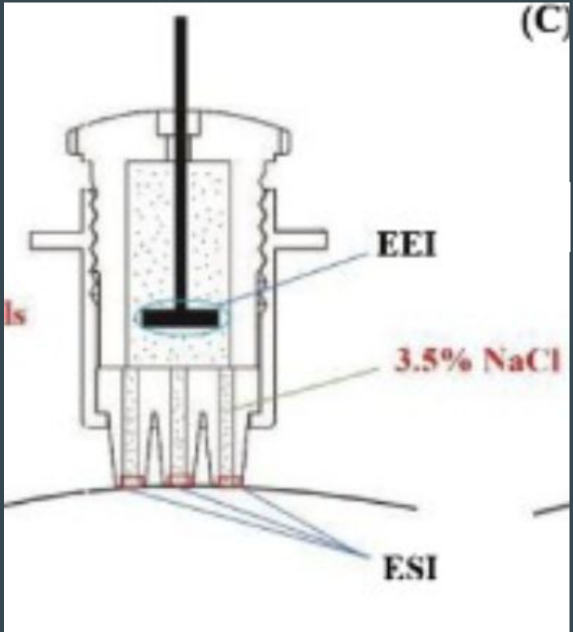


Diagram of Semi Wet Electrode

Acknowledgement

Thank you to Dr. Gert Cauwenberghs and the Beng 186B TAs for their constant support and help.

References

1. https://www.sciencedirect.com/science/article/pii/S0925400518315934?via%3Dihub
2. https://www.sciencedirect.com/science/article/pii/S0925400516316318
3. https://www.sciencedirect.com/science/article/pii/B9780124114708000076#f0015
4. Dry-Contact and Noncontact Biopotential Electrodes:
5. Highly conformable stretchable dry electrodes based on inexpensive flex substrate for long-term biopotential (EMG/ECG) monitoring - ScienceDirect
6. PPT - Biopotential Electrodes PowerPoint Presentation, free download - ID:5200117 (slideserve.com)
7. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5728108/
8. EMG/EEG Disc Electrode | Biofeedback | Disc electrode | 50 pcs. – Neuro Store (neuro-store.com)