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ABSTRACT
The unwanted signals that arise in electrocardiography are discussed. A technical background of electrocardiography is given, along with teaching techniques that educate students of medical instrumentation to solve the problems caused by these signals. (MJH)

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PROBLEMS IN RECORDING THE ELECTROCARDIOGRAM

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The object of the instrumentation system in electrocardiography is to measure the electrical signal produced by the heart. The signal is picked up by electrodes, conducted by cables, amplified and displayed or recorded. There are a number of artifacts (unwanted signals) that are added to the wanted cardiac signal. If these artifacts are large enough to interfere with proper diagnosis, then they constitute a problem.

This paper lists the various problem areas, details the causes of these problems, outlines solutions to these problems and presents teaching techniques that educate students to solve these problems.

Motion Artifact

When electrodes are pushed or moved on the skin, the ECG trace wanders and undergoes large unwanted excursions, which are known as motion artifacts. These artifacts are caused by movements of the electrical double layer when using older plate-type electrodes. But this is not a problem in modern, recessed (floating) Ag-AgCl electrodes. This is easily proved by placing paste between two electrodes as shown in Fig. 1. The electrodes can be moved with respect to each other with little artifact.[1] Yet when these electrodes are placed on the skin, motion artifacts appear. This is due to variations in the skin potential which exist between the inside and outside of the skin.[2] These variations can be made very small by light abrasion (20 times with fine sandpaper) of the electrode site, resulting in very small motion artifact. After this skin preparation only mild pastes (Hewlett-Packard Redux-Creme) can be used or irritation results.[3]

I teach these concepts in a course Biomedical Instrumentation by providing handout material and a series of questions to guide the student:

1) Give Edelberg's model for skin potential, explaining what each element represents. (See Fig. 2 for components due to epidermis and sweat duct)

2) Explain how and why the skin potential changes a) if sweat rises in the duct, b) if sweat overflows the duct, c) if there is simple hydration of the corneum.

3) Sketch a typical skin potential response to pressure stimulation.

4) What is the probable origin of the local potential response? List supporting evidence.

5) Plot: a) skin potential, b) changes in skin potential, versus amount of abrasion.

6) Discuss the effects on abraded skin of a) harsh pastes, b) mild pastes.

One of these concepts is also emphasized in a laboratory experiment on the ECG, where the student is told to tap the electrode and observe the resulting artifact. Then the student jumps up and down while recording the ECG. These concepts could be further emphasized by the development of a separate laboratory experiment on skin potential and motion artifacts. I hope to develop such an experiment in the coming year.

Electromagnetic Interference

THe most common type of electromagnetic interference appearing on the ECG trace is of 60 Hz origin. At this low frequency, it is convenient to separately consider problems due to magnetic and electric fields.[4] Fig. 3 shows that the magnetic field intersects the area of the loop formed by the cables leading to the amplifier, resulting in a magnetically induced voltage. The obvious solution to this problem is to twist the cables together to reduce the effective area of the loop formed by the cables as shown in Fig. 4.

Fig. 3 also shows that the electric field causes a displacement current to flow through the body to ground. The resulting IZ drop across the ground electrode impedance produces a 60 Hz common mode voltage on the body. If the electrode impedances are unequal, this common mode voltage is converted to differential voltage at the amplifier input. The problem may be solved by increasing the amplifier common mode input impedance or by using a driven right leg amplifier[4] (see Fig. 5).

High frequency electromagnetic interference may be due to sources such as modulated RF signals, computers, motors, ignition, electrocautery and diathermy. The problem may be solved by using filters or shields either at the source or at the amplifier or both[5].

Static electricity can also cause a problem when the humidity is low and charges build up on the synthetic materials frequently used in hospitals. The problem may be solved by attention to proper shielding, grounding, amplifier design and electrode application[6].

I teach these concepts in a course <u>Medical Instrumentation</u>[7] by providing a series of questions to guide the student when reading the text:

1) Give the formula for common mode rejection ratio (CMRR). Define each term. Why is CMRR important?

2) 1 μA of 60 Hz current flows through a 20 kΩ right leg electrode

which grounds the body. What is the common mode voltage on the body?

3) 60 Hz interfering common mode voltage on the body is 50 mV. Electrode impedances are 10 kΩ and 20 kΩ. How much interference is measured by the amplifier? Amplifier $Z_{in} = 1$ MΩ.

4) Assume electrode impedances are 10 kΩ. How big should the network resistors be in the aVF lead configuration so the potential between the wrists will be reduced 5% due to loading?

5) Show the design for a "driven right leg" amplifier. Explain its operation and need.

6) Design a network which will protect an ECG amplifier during defibrillation.

7) If the standardization button is pressed for 10 seconds, what waveform results on an ECG recorder?

8) Show the design for a buffer amplifier. Is it required? Why?

9) Show the design for a circuit which will indicate that an electrode has become disconnected. Why is this useful?

10) Sketch the E - I characteristics of a current limiter. If the typical zero bias resistance is 0.2 MΩ, how could this device increase 60 Hz interference?

Another mechanism used to teach the solution to interference problems is through a programmed learning format. In our course, Medicine and Clinical Engineering, a typical question from the text[8] is:

"Interference can enter the input circuit of an amplifier by three types of coupling: ...., ... and ...." (Answers: capacitive, inductive, resistive). Further questions then probe the students' knowledge of the causes and cures of each of these types of interference.

Some of these concepts are emphasized in a laboratory experiment where the student assembles a biopotential amplifier. The student measures the common mode voltage on the body. He also measures the 60 Hz interference with electrode cables close together and forming a loop with the largest possible area.

Electromyographic Interference

When a subject is exercising, the EMG signal is largest over muscular areas. This form of motion artifact can be minimized by placing electrodes on bony, relatively less active sites. Coaching the subjects to relax the muscles around the electrode area also helps to reduce the EMG level. When possible, the electrodes can be placed at each end of the sternum. See Fig. 6. This provides a large ECG signal with minimum EMG.

This concept is emphasized in a laboratory experiment on the ECG. The student tenses his muscles under the arm leads and compares the amount of artifact with that obtained while relaxed.

Television Presentations

Concepts regarding the ECG are also emphasized by a classroom color television series on Medical Instrumentation. The presentation titled "Dog Surgery" shows placement of needle electrodes, use of amplifier, recorder and controls, fibrillation and defibrillation.

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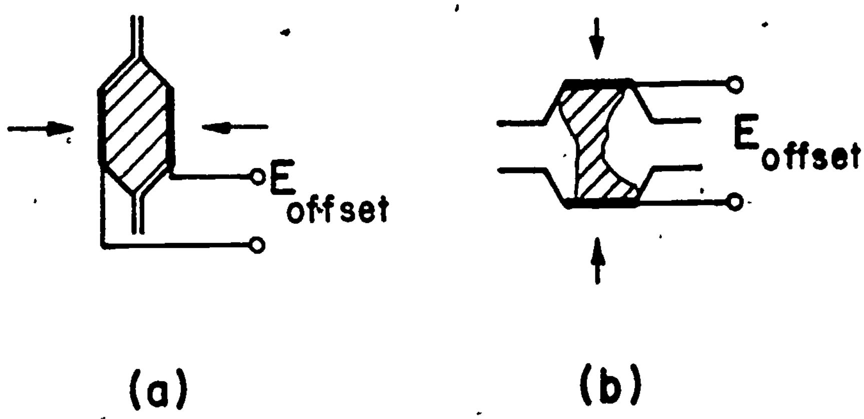

Fig. 1. Two electrodes placed face-to-face with paste between

(a) force on electrodes causes little artifact

(b) separation causes little artifact as long as there is a paste bridge

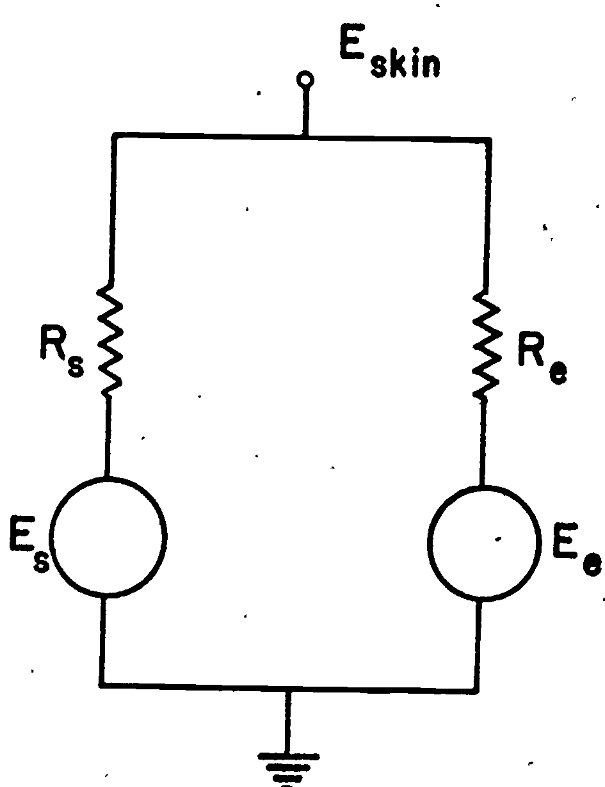

Fig. 2. Edelberg's skin model. A change in any of the four variables shown can change the skin potential.

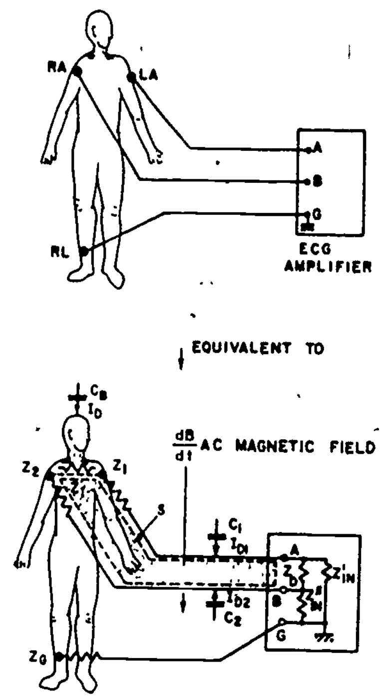

Fig. 3. Typical ECG recording configuration lead I and the equivalent circuit. RA is right arm; LA is left arm. RL is right leg. The capacitors simulate the entry of displacement currents. Dotted lines indicate the area S of the conductive loop.

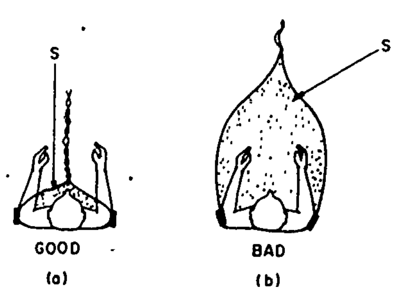

Fig. 4. Electrode lead placement illustrating the magnetic induction loop. (a) Correct lead placement: twisted leads run close to the body yielding small S. (b) Incorrect lead placement: area S as large as $0.2\ m^2$.

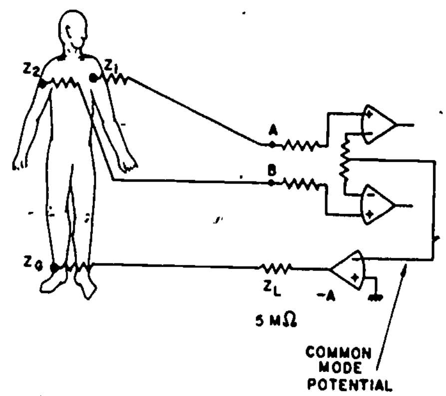

Fig. 5. Driven right-leg configuration.

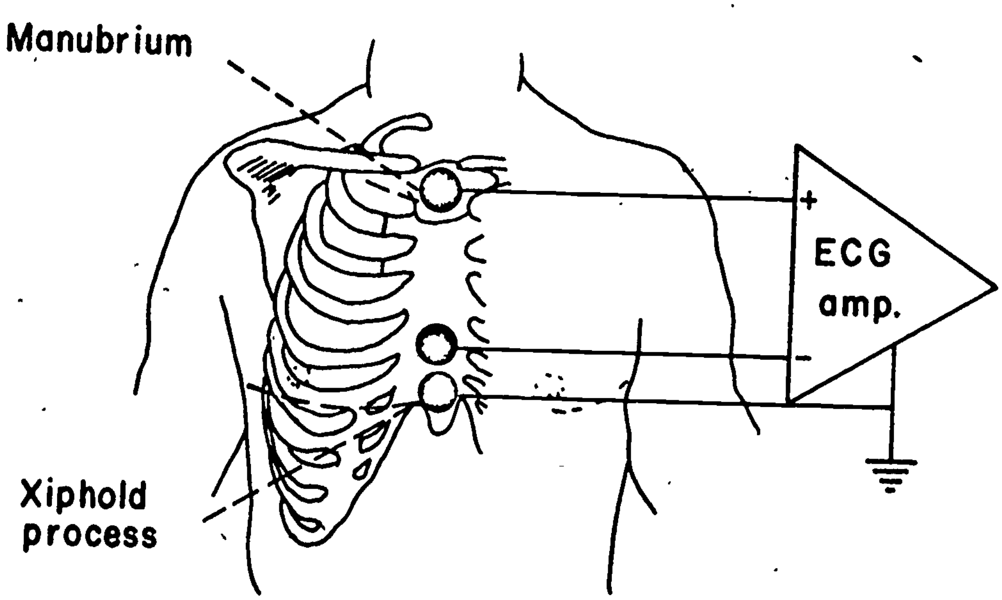

Fig. 6. Electrode position for minimum EMG artifact. The ground electrode can be placed at any convenient location.