1.4: EKG Machinery and Setup

Note: There are many, many types of EKG electrode patches. Some are a simple sticker where the adhesive and gel pad are combined, some have a small metal button or clip where the wire for the leads attach. This EKG learning module does not endorse any specific brand or type of EKG electrode or patch.

The gel pad on the above EKG electrode improves conduction from the surface of the chest to the lead. Most electrodes have a similar compound and mechanism to improve the lead's ability to detect electrical activity.

The electrode also incorporates an adhesive that sticks the pad to the chest wall. The adhesive alone is usually adequate to adhere the electrode well, but a poorly adhered electrode will not detect electrical activity adequately (or at all). Common confounding factors that can make it harder for the electrode to adhere to the chest wall include excessive lotion or topical oil used on the skin, extensive sweating or diaphoresis, and hair. It is very acceptable and encouraged to shave or clip the chest of a patient who needs an EKG but has too much hair to allow the electrodes to stick. It is also acceptable to use tape or other adhesives to reinforce the electrode’s adhesive.
There are many, many types of monitors that serve a variety of purposes. Some units are designed for monitoring purposes only, others are multi-functional and can include many features like defibrillation, external pacing, and monitoring of other clinical data like blood pressure and end tidal CO2. This EKG interpretation lesson series does not endorse any one EKG machine type or brand over the others.

While the design of the machines are very different, their purposes as EKG monitors are all functionally the same: they all measure and interpret the flow of electrical activity. This course does not endorse or recommend any specific type of EKG monitor or machine over others.

Most hospitals monitor patients via at least 3 leads simultaneously. An EKG lead is a particular electrical “view” of the heart and is representative of flow of electricity toward and away from 2 points in the heart. The setup looks like this:

Each lead is named and will be labeled: RA, LA, RL, and LL. The easiest way to remember this is RA = right arm, LA = left arm, RL = right leg, LL = left leg. The leads can be placed on the extremities or as is pictured on the corresponding
corner of the trunk.

Lead II is the most commonly interpreted with regards to rhythm and is usually the first lead students learn to interpret. It goes diagonally from the right upper chest to the left lower chest in the same positions a defibrillator or AED would be in. Lead I goes laterally across the chest, measuring electricity from a positive electrode on the left upper chest and a negative electrode on the right upper chest. Lead III measures vertically across the left chest wall. Its negative electrode is the left upper chest and its positive electrode is the left lower chest. Notice that the positive electrode for lead I is the same as the negative for lead III - every physical electrode placed is capable of measuring both positively and negatively in the way the left upper chest electrode does.

![Image of an EKG waveform and Einthoven's Triangle](https://med.libretexts.org/Bookshelves/Nursing/An_EKG_Interpretation_Primer_(Christianson_et_al.)/01%3A_Chapters/1.04...)

Figure \(\PageIndex{4}\): Image 4, Sinus Rhythm

The above picture is normal sinus rhythm in leads I, II, and III. Notice the differences for each. The P waves in leads I and II are upright, as electricity in the heart flows primarily toward their positive leads. The P wave in lead III however is biphasic and somewhat flattened. That is because electricity flows toward both the positive and negative electrodes (as the electricity flows in a down-left manner, and both positive and negative electrodes are to the left of the heart). The QRS complexes have similar morphological differences due to the differences in lead positioning.

**Einthoven’s Triangle**

A standard 12 lead EKG measures 12 “views” of the heart using 10 electrodes. 6 of the leads are bipolar, which means they have both an electrode measuring both positive and negative activity. Thanks to mathematical calculations, these 6 bipolar leads only require 4 electrodes: the 3 pictured above and a ground electrode, which helps remove interference and artifact (the above setup is possible without the ground electrode). 3 of the leads are considered to be “virtual leads,” or leads that are not physically on the patient but have been calculated mathematically based on the 3 existing electrodes. The triangular arrangement of electrodes is referred to as Einthoven’s triangle.
The virtual leads are aVL, aVR, and aVF. You can remember which is which by remembering that VL is the virtual left lead, VR is the virtual right lead, and VF is the virtual inferior lead. It can be difficult to visualize, but the positive electrode for aVR is RA, the negative electrode is a virtual electrode that is directly between LA and LL. This lead is calculated using a formula based on the electrical activity tracked on the LA and LL electrodes. Similarly, aVL uses LA as a positive electrode and uses a virtual electrode between RA and LL that is mathematically calculated as a negative electrode. The aVF lead uses LL as a positive electrode and a virtual negative electrode between RA and LA.

Above is a normal sinus rhythm in leads aVR, aVL, and aVF. Notice that aVR is almost a perfect inversion of lead II. Refer to Einthoven's triangle:
Notice that lead II and aVR are almost (but not completely) parallel in their orientation, but their direction is opposite? The negative lead for lead II is the positive lead for aVR, and the virtual lead between LL and LA is the negative lead for aVR. Lead LL is the positive lead for lead II. Compare all 6 of the bipolar leads in this normal sinus rhythm EKG:

II and aVR are almost perfect inversions, which makes sense when you consider the lead orientation as we did above. II, III and aVF are also very similar, which also makes sense because the LL lead is the positive electrode for all 3 of these leads. The negative virtual electrode for aVF is directly between the negative electrodes for II (RA) and III (LA). Notice that the morphology of the entire aVF lead is essentially an intermediary of II and III: the P wave for aVF is taller than it is in lead III but shorter than it is in lead II. The QRS is complex has an amplitude (height) that is taller than III but shorter than II, the S in particular is not as low in amplitude (deep) as in lead II but is lower than in lead III. The T wave is also larger than in lead III, but smaller than lead II.

aVL is a stranger lead if directly compared to I, II, and III. While it does have some things in common with lead I, including a shared positive electrode (LA), its QRS complex is more biphasic (goes both positively and negatively) than lead I. The P wave is also flatter, and the T wave is barely visible. This has to do with the placement of the negative virtual electrode, between the RA and LL electrodes; the electricity flows simultaneously in both directions, and the amount of electricity going toward both electrodes is closer to equal than it is in lead I. This leads to flattened P and T waves because simultaneous positive and negative electrical flow registers on the EKG graph as flat. This is because the computer balances the negative against the positive, so for example electricity measuring 3 mV going toward the
positive electrode would normally register as an upward inflection on the EKG that is 3 small boxes high. However, if there is also 3 mV of electricity going toward the negative electrode at the same time, the computer interprets this as 0 neg amplitude because the 3 mV flowing towards the negative electrode cancels out the 3 mV flowing towards the positive.

EKG interpretation in multiple leads can be more challenging because there is more to consider regarding electrical flow, directionality, and how the leads interpret the electrical flow. It is important to be able to recognize at least basic features of the EKG in each lead, as well as what is normal for each lead, because most arrhythmias need to be confirmed in multiple leads. Confirmation in more than one lead is important because EKG machines, electrodes, the wires themselves, and placement of electrodes can all cause abnormal readings, and confirming an arrhythmia in another lead is done to ensure an arrhythmia is, in fact, an electrical abnormality with the heart and not a mechanical malfunction or human error in lead placement.

### Lead Reversals

Human error is common in obtaining EKGs, and while lead placement is not always a precise measurement, it is important to double check the correct wires are connected to the correct electrodes. If you accidentally mixed 2 of your leads up, there are also morphological changes to the EKG that are predictable, identifiable as a lead reversal, and can be cause for alarm if they are not correctly identified as a lead reversal.

If you reverse the LA and RA leads, for example, lead I inverts:

![Image of EKG with reversed leads](https://med.libretexts.org/Bookshelves/Nursing/An_EKG_Interpretation_Primer_(Christianson_et_al.)/01%3A_Chapters/1.04...)

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This is because the negative RA electrode is now in the LA position, and the positive LA electrode is now in the RA position in error. You will also notice that leads II and III have switched: lead III’s negative electrode, LA, is now in the RA position (normally lead II’s negative electrode), and lead II’s negative electrode RA is now in the LA position. The differences in leads II and III are not particularly marked in this example of lead reversal, but you will notice that the P and T waves in lead III are taller than they are in lead II which is normally opposite. The virtual leads aVL and aVR also reverse (not pictured in EKG graph), so aVL will look like aVR normally does and vice versa.

If you reverse the LA and LL leads, this is the result:

Lead III is inverted, which makes sense because LA is normally the negative electrode and LL is normally the positive electrode for this lead. When they are reversed, you will notice all of the waves are inverted compared to correct placement. You will also notice that lead I looks more like lead II with a taller P and T wave; that’s because the normal leads for lead I are now in the position they should be for lead II (RA in the correct position, LA in the position of LL). Lead II is essentially now lead I, as its positive lead (LL) is incorrectly in the LA position.

All of the leads, when reversed, will show predictable changes that have to do with the physical lead placement. This primer will not go into deeper detail about lead reversal, but know that there will be at least subtle changes in most of the
leads if there are lead reversals, as most modern EKG machines interpret data and use mathematical calculations based on the physical leads to predict virtual leads, like in aVR, aVL, and aVF. It is also important to consider that correct electrode placement, with or without lead reversal issues, is important for the same reason.

The first 4 leads, including the ground lead (RL) are the same as they are for our previous readings. This time, we are adding 6 additional unipolar leads, labeled V1 through V6 on the diagram. Unipolar leads are a little different from bipolar leads. A bipolar lead measures electricity in 2 directions - toward a positive electrode and toward a negative electrode. A unipolar lead only measures toward a positive lead. You will notice that, despite not having a negative lead, leads V1 through V6 do have negative deflections on them in the same way leads I through aVF do. This is because the “negative electrode” in this case is similar to the virtual electrodes in leads aVR-aVF. The computer uses a mathematical calculation of all of the other leads to produce a virtual electrode. This time, the virtual electrode is intended to be near the center of the heart. If you compare it to an anatomic cross-section, the V leads evaluate the transverse plane while leads I-aVF evaluate the coronal plane:

It is important to make sure leads are placed correctly for a 12 lead. V1 is the only lead that is located to the right of the sternum. V1 and V2 are placed at the 4th intercostal space to the right and left of the sternum, respectively. It is recommended to physically palpate the first 4 intercostal spaces when you place leads V1 and V2; the location is anatomically lower on the chest wall than it appears at a glance. V3 and V4 are placed next, both in the 4th intercostal
space. V4 should be placed in the 4th intercostal space directly below the nipple - this is also about the mid-clavicular line. V3 is placed in the 4th intercostal space directly, but laterally placed halfway between V2 and V4.

V5 and V6 are placed in the 5th intercostal space. V6 is placed horizontally along the mid-axillary line in the 5th intercostal space. V5 is placed in the 5th intercostal space, halfway between V4 and V6.