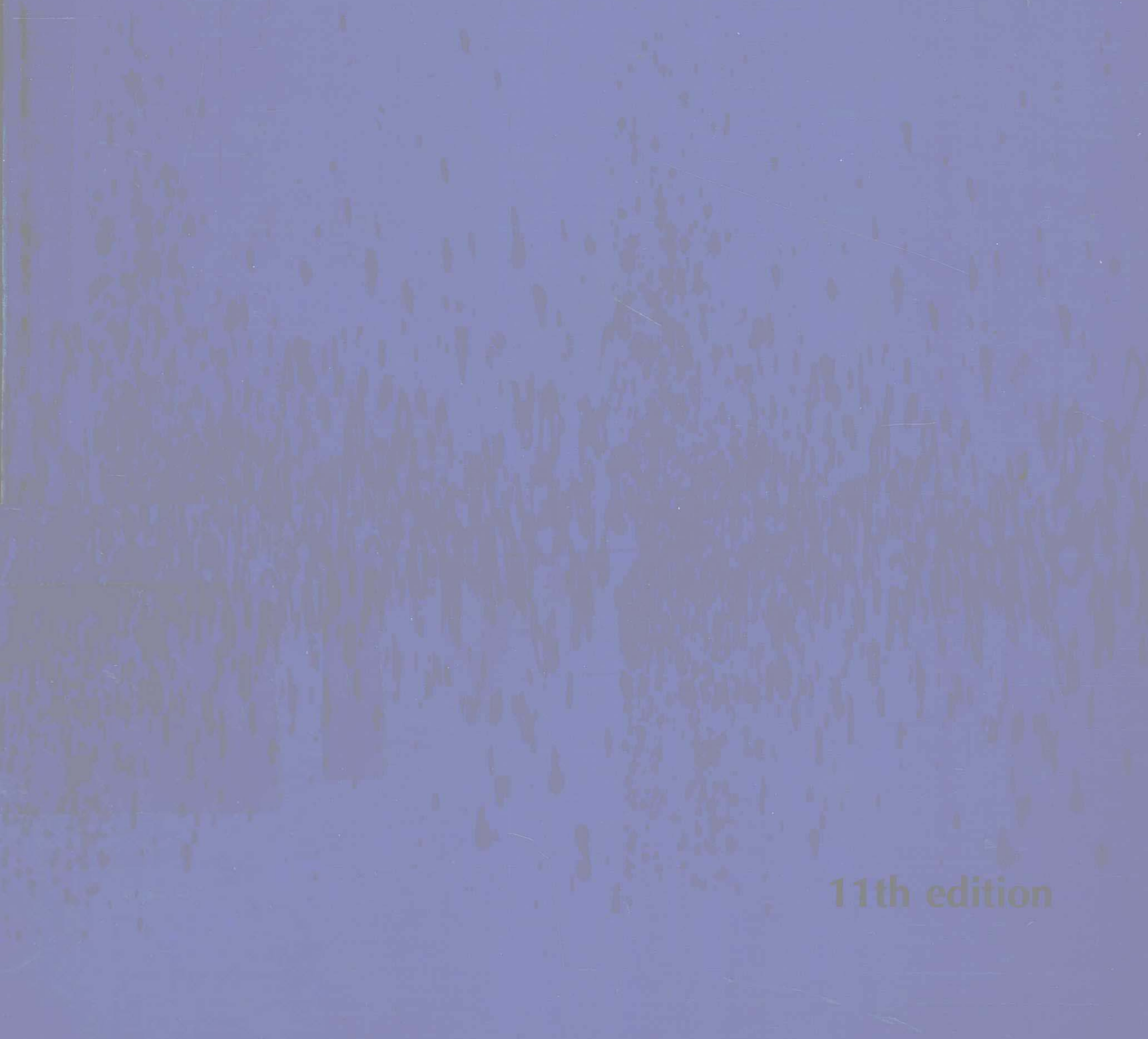
Principles of Clinical Electrocardiography

M.J. Goldman



11th edition

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Principles of Clinical Electrocardiography

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Preface

It is the author's intention to present in this volume the basic concepts of electrocardiography and their clinical application. He realizes that material so presented must be simplified and that an exhaustive and detailed treatment of the subject matter to be covered will not be possible.

Emphasis has been placed on the unipolar leads. To one who first learned electrocardiography by memorizing patterns in the bipolar standard leads and later followed the development of unipolar electrocardiography, the latter offers a more logical approach to the subject material. Vector analysis of the ECG offers an intelligent means of understanding the electrical potentials generated from the heart. There should be no major disagreement between vector and unipolar electrocardiographic analysis. Both are descriptive of the same phenomena, the former offering an evaluation of the electrical potentials as oriented in space and the latter as reflected in the resulting electrocardiographic pattern.

A knowledge of basic electrophysiologic principles is essential in the understanding of the ECG. These are emphasized throughout the text. Such information permits a more logical and meaningful appreciation of electrocardiography.

The author cannot too strongly emphasize the fact that the ECG is a laboratory test only. Like all laboratory findings, an abnormal electrocardiographic tracing is significant only when interpreted in the light of clinical findings. Ideally, the person best qualified to interpret the ECG is the physician caring for the patient.

The chapter on spatial vectorcardiography and corrected orthogonal lead systems is intended to give the reader an insight into this relatively new field and not as a comprehensive discussion of the subject.

For the eleventh edition, new concepts pertaining to the differential diagnosis of transmural versus nontransmural myocardial infarction have been introduced; a section has been added on left anterior conduction delay; and a third appendix describes the application of statistics to the interpretation of the ECG. The section on electrical pacing has been expanded, and 44 new ECGs have been added.

We are most gratified with the acceptance this Review has received among students and physicians both here and abroad. Spanish, Italian, Japanese, Polish, Portuguese, French, and Greek translations are now available; German and Turkish translations are in preparation.

The many letters received are hereby acknowledged and are most welcome.

Mervin J. Goldman, MD

San Francisco
August, 1982

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Introduction to Electrocardiography | 1

The electrocardiogram (ECG) is a graphic recording of the electrical potentials produced in association with the heartbeat. The heart is unique among the muscles of the body in that it possesses the property of automatic rhythmic contraction. The impulses that precede contraction arise in the conduction system of the heart. These impulses result in excitation of the muscle fibers throughout the myocardium. Impulse formation and conduction produce weak electrical currents that spread through the entire body. By applying electrodes to various positions on the body and connecting these electrodes to an electrocardiographic apparatus, the ECG is recorded. The connections of the apparatus are such that an upright deflection indicates positive potential and a downward deflection indicates negative potential.

USEFULNESS OF THE ELECTROCARDIOGRAM

With advances in electrocardiography, the accuracy of electrocardiographic diagnosis has been greatly increased. The ECG is of particular value in the following clinical conditions:

(1) Atrial and ventricular hypertrophy.

(2) Myocardial ischemia and infarction: Multiple leads, vectorcardiograms, and modern exercise testing have increased the accuracy of diagnosis and of estimates of extent of disease.

(3) Arrhythmias: Not only can more exact diagnoses be made, but unipolar and intracardiac electrocardiography have also contributed substantially to our basic understanding of the origin and conduction of abnormal rhythms.

(4) Pericarditis.

(5) Systemic diseases that affect the heart.

(6) Effect of cardiac drugs, especially digitalis and quinidine.

(7) Disturbances in electrolyte metabolism, especially potassium abnormalities.

Caution to the Beginner

The ECG is a laboratory test only and is not a sine qua non of heart disease diagnosis. A patient with an organic heart disorder may have a normal ECG, and a perfectly normal individual may show nonspecific electrocardiographic abnormalities. All too often a patient is relegated to the status of a cardiac invalid solely on the basis of some electrocardiographic abnormality. On the other hand, a patient may be given unwarranted assurance of the absence of heart disease solely on the basis of a normal ECG. The ECG must always be interpreted in conjunction with the clinical findings. In general, the person best qualified to interpret the ECG is the physician caring for the patient.

ELECTROCARDIOGRAPHIC APPARATUS

In modern electrocardiography, 2 types of apparatus are used: the string galvanometer and the radio amplifier. The former records its pattern on photographic paper which must then be developed. It requires more experience to operate, and caution must be taken to prevent damage to the valuable string. The radio amplifier has been combined with a direct writer; it is a compact, light, and mobile unit which is very simple to operate, and there is much less chance of damaging the machine by technical errors of operation. It has the additional advantage of producing an instantaneous recording, thus making the record immediately available for interpretation. Many modern machines record multiple (3 or 6) leads simultaneously.

Oscilloscopic viewing of the ECG is commonly used in clinical medicine. This produces a constant electrocardiographic pattern on a fluorescent screen, and permanent records can be obtained by connecting the machine to a direct-writing apparatus. Such pieces of equipment are now routine in coronary and intensive care units and in surgery.

Small electrocardiographic tape recorders can be attached to a patient and continuous recordings obtained while the patient is ambulatory (or at rest) for 24-hour periods. The tape is then reviewed by the physician. This is of special value in the study of patients with arrhythmias and myocardial ischemia.

ECGs can be transmitted via telemetry or telephone lines, thus permitting constant or temporary

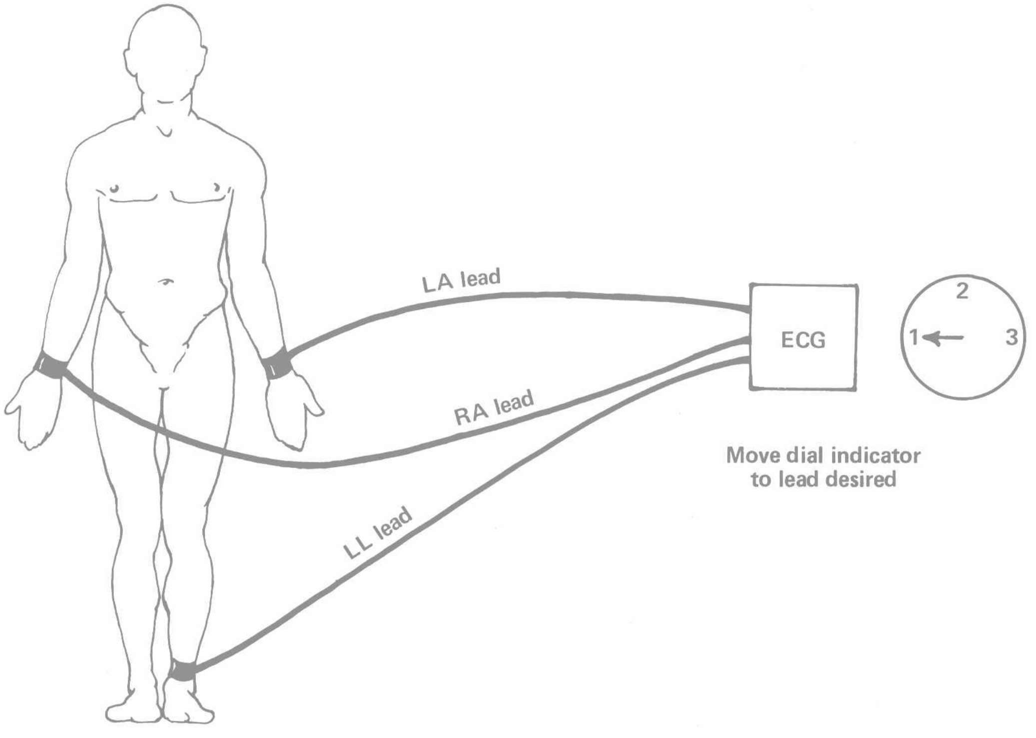


Figure 1–1. Standard leads.

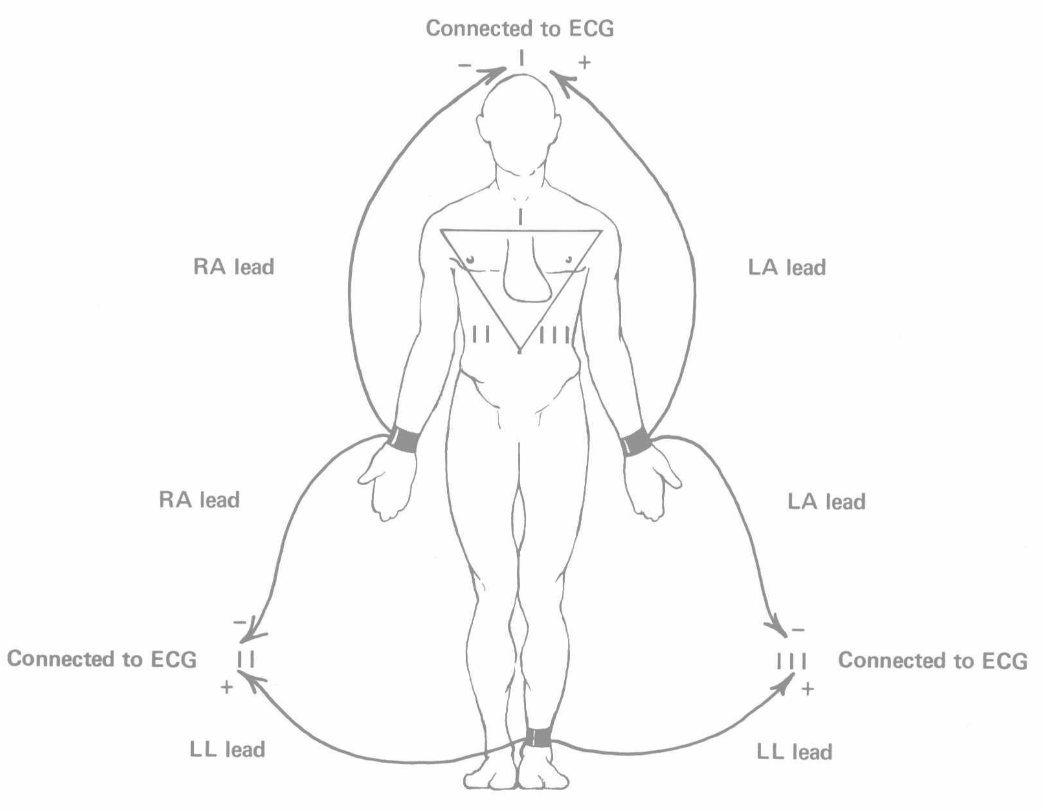


Figure 1–2. Connections for bipolar standard leads I, II, and III.

monitoring and interpretation by a physician many miles from the patient. Memory loops are available to record events prior to the onset of an arrhythmia. Computer facilities are available not only for electrocardiographic interpretation but for the recognition and quantitation of arrhythmias.

BIPOLAR STANDARD LEADS

The bipolar standard leads (I, II, and III) are the original leads selected by Einthoven to record the electrical potentials in the frontal plane. Electrodes are applied to the left arm, right arm, and left leg. Proper skin contact must be made by rubbing electrode paste on the skin. The LA (left arm), RA (right arm), and LL (left leg) leads are then attached to their respective electrodes. By turning the selector dial to 1, 2, and 3, the 3 standard leads (I, II, and III) are taken.

All electrocardiographic machines also have a right leg electrode and lead. This acts as a ground wire and plays no role in the production of the ECG. In areas where there is electrical interference, it may be necessary to run a ground wire from the bed or the machine to an appropriate ground (water pipe or steam pipe).

Electrical Potential

The bipolar leads represent a difference of electrical potential between 2 selected sites.

Lead I = Difference of potential between the left arm and the right arm (LA − RA).

Lead II = Difference of potential between the left leg and the right arm (LL − RA).

Lead III = Difference of potential between the left leg and the left arm (LL − LA).

The relation between the 3 leads is expressed algebraically by Einthoven's equation: lead II = lead I + lead III. This is based on Kirchoff's law, which states that the algebraic sum of all the potential differences in a closed circuit equals zero. If Einthoven had reversed the polarity of lead II (ie, RA − LL), the 3 bipolar lead axes would result in a closed circuit (Fig 1–17), and leads I + II + III would equal zero. However, since Einthoven did make this alteration in the polarity of the lead II axis, the equation becomes: I − II + III = 0. Hence II = I + III.

The electrical potential as recorded from any one extremity will be the same no matter where the electrode is placed on the extremity. The electrodes are usually applied just above the wrists and ankles. If an extremity has been amputated, the electrode can be applied to the stump. In a patient with an uncontrollable tremor, a more satisfactory record may be obtained by applying the electrodes to the upper portions of the limbs.

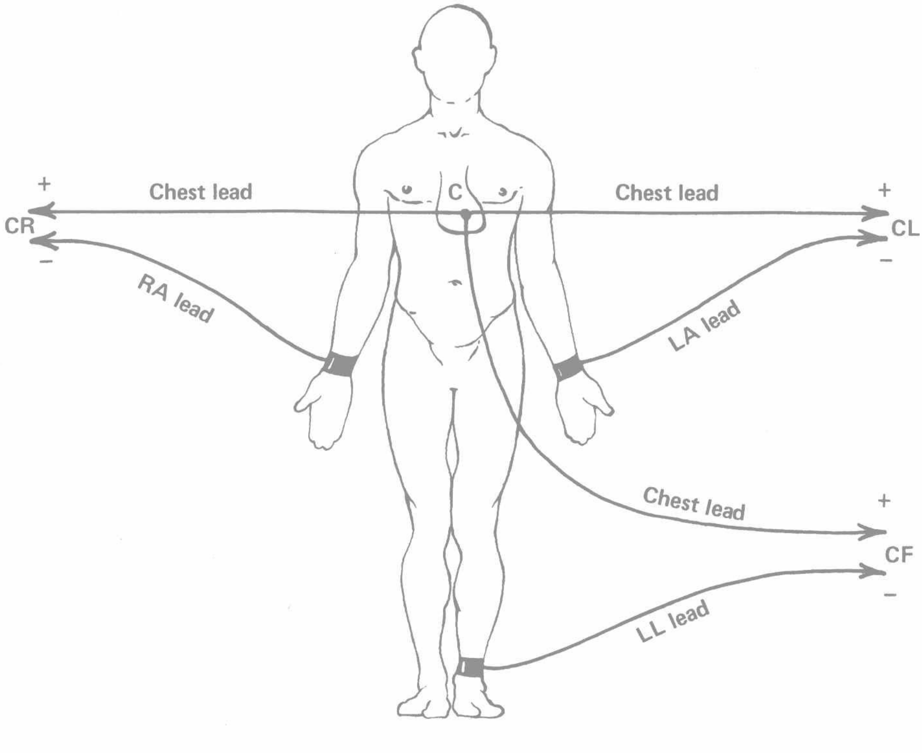


Figure 1–3. Connections for bipolar chest leads CR, CL, and CF.

BIPOLAR CHEST LEADS

Bipolar chest leads record differences of potential between any given position on the chest (C) and one extremity. Before unipolar electrocardiography was introduced, the left leg (F) was used as the "indifferent" electrode, and the leads were called CF leads. Less commonly, the right arm (CR leads) or the left arm (CL leads) was used. It was assumed that the left leg (or right or left arm) was so remote from the heart that it would act as an "indifferent" electrode and not interfere with the chest potential. However, it is now realized that the potentials in the extremities can appreciably alter the pattern of the chest lead. For this reason CF, CR, and CL leads are not frequently used today.

A special bipolar chest lead (Lewis lead) is of value in amplifying the waves of atrial activity and thereby clarifying the mechanism of an atrial arrhythmia. The right arm electrode is placed in the second intercostal space to the right of the sternum. The left arm electrode is placed in the fourth intercostal space to the right of the sternum. The tracing is then recorded on lead I. The above 2 electrodes may be interchanged (RA and LA). This will reverse the polarity of all the complexes, but it will not alter the interpretation since the basic purpose is to identify atrial activity.

UNIPOLAR LEADS (Extremity Leads, Precordial [Chest] Leads, Esophageal Leads)

Unipolar leads (VR, VL, VF, multiple chest leads "V," and esophageal leads "E") were introduced into clinical electrocardiography by Wilson in 1932. The frontal plane unipolar leads (VR, VL, VF) bear a definite mathematical relationship to the standard (I, II, III) bipolar leads (see p 13). The precordial (V) leads record potentials in the horizontal plane without being influenced by actual potentials from an "indifferent" electrode used in recording bipolar chest leads. One concept must be clearly understood: A unipolar precordial (or esophageal) lead does not record only the electrical potential from a small area of the underlying myocardium; it records all of the electrical events of the entire cardiac cycle as viewed from the selected lead site.

All modern electrocardiographic machines are constructed so that augmented extremity leads can be taken with the same hookup as used for standard leads by turning the selector dial to aVR, aVL, and aVF. Unipolar chest leads are taken by applying the chest lead and its electrode to any desired position on the chest and turning the selector dial to the V position. Multiple chest leads are taken by changing the position

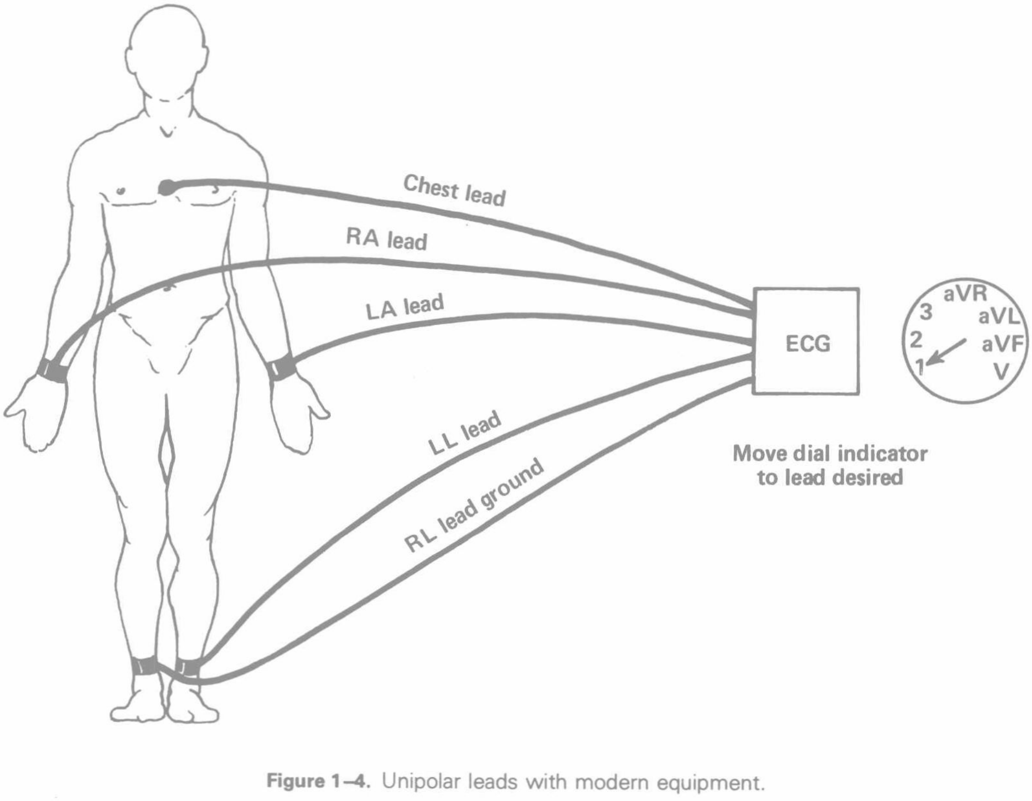


Figure 1–4. Unipolar leads with modern equipment.

of the chest electrode (Fig 1–9). Unipolar esophageal leads are taken by attaching the esophageal lead to the chest lead and turning the selector dial to the V position (Fig 1–14).

A universal lead selector is available for a 3-lead electrocardiographic apparatus. With this unit attached, the standard, unipolar extremity, and chest leads can be taken by simply rotating the selector dial as is done with all modern electrocardiographic machines.

IMPROVISED UNIPOLAR LEADS USING AN INDIFFERENT ELECTRODE

If a modern electrocardiographic machine or universal lead selector is not available, an electrocardiograph that can record standard leads I, II, and III can be used to obtain perfectly satisfactory unipolar leads. To do so, one first constructs an indifferent electrode. This is easily made by fastening 3 separate lengths of insulated copper wire (each about 4 feet long) together at one end with a battery clip. This end becomes the central terminal (T). The 3 free ends are connected to the LA, RA, and LL electrodes. The central terminal is connected to the RA lead of the electrocardiograph. The LA lead becomes the exploring electrode for any desired unipolar lead. All such leads are taken with the selector dial on lead I.

In principle, the unipolar leads attempt to represent potentials in a given lead axis and not differences in potential. Since it is generally accepted that the sum of the potentials of the 3 extremity leads is zero (RA + LA + LL = 0), the connection of these 3 extremity leads (the central terminal) will for all clinical purposes result in a zero potential.

UNIPOLAR EXTREMITY LEADS

Unipolar Nonaugmented Extremity Leads VR, VL, VF

These have been replaced by the augmented extremity leads aVR, aVL, and aVF and are not commonly taken.

Using the indifferent electrode (RA + LA + LL) as one terminal and placing another electrode on the right arm, a bipolar lead can be taken. This represents the difference between the potential of the right arm and the zero potential of the central terminal (RA − 0 = RA). Therefore, the "actual" potential of the right arm is recorded. Although it is technically a bipolar lead, it represents a unipolar lead since one of the potentials is zero. This is designated as VR (vector of right arm). The left arm (VL) and left leg (VF) potentials are obtained in the same way. The selector dial is set on lead I (Fig 1–6).

(1) To take VR, the LA lead of the machine is attached to an electrode placed on the right arm at a different site from the RA electrode connected to the central terminal.

(2) To take VL, the LA lead of the machine is attached to an electrode on the left arm.

(3) To take VF, the LA lead of the machine is attached to an electrode on the left leg.

Augmented Extremity Leads aVR, aVL, aVF

By a slight change in technique from above (this is automatically accomplished by all modern electrocardiographic machines), the amplitude of the deflections of VR, VL, and VF can be increased by about 50%.* These leads are called augmented unipolar extremity leads and are designated as aVR, aVL, and aVF. It must be emphasized that the only difference between leads VR, VL, and VF and leads aVR, aVL, and aVF is this difference in amplitude. In routine electrocardiographic practice, the augmented leads have replaced the nonaugmented unipolar extremity leads because they are easier to read. (Hereafter in this text, the term "extremity leads" will refer to the augmented leads.)

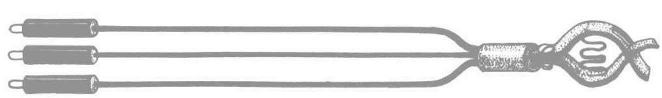


Figure 1–5. Indifferent electrode.

*Using lead aVR as an example, this can be shown as follows. Since aVR represents a difference of potential between the right arm (RA or VR) and the average of the potential of the left leg and left arm, the following equation (1) can be established:

$$(1)\ aVR = RA - \left[\frac{LL + LA}{2}\right]$$

By changing signs in (1):

$$(2)\ aVR = RA + \left[-\frac{LL + LA}{2}\right]$$

From Einthoven's equation it is known that:

$$(3)\ RA + LA + LL = 0$$

By subtracting LA + LL from both sides of (3):

$$(4)\ RA = -(LA + LL)$$

By substituting equation (4) in (2):

$$(5)\ aVR = RA + \left[\frac{RA}{2}\right] = 3/2\ RA\ (\text{or } 3/2\ VR)$$

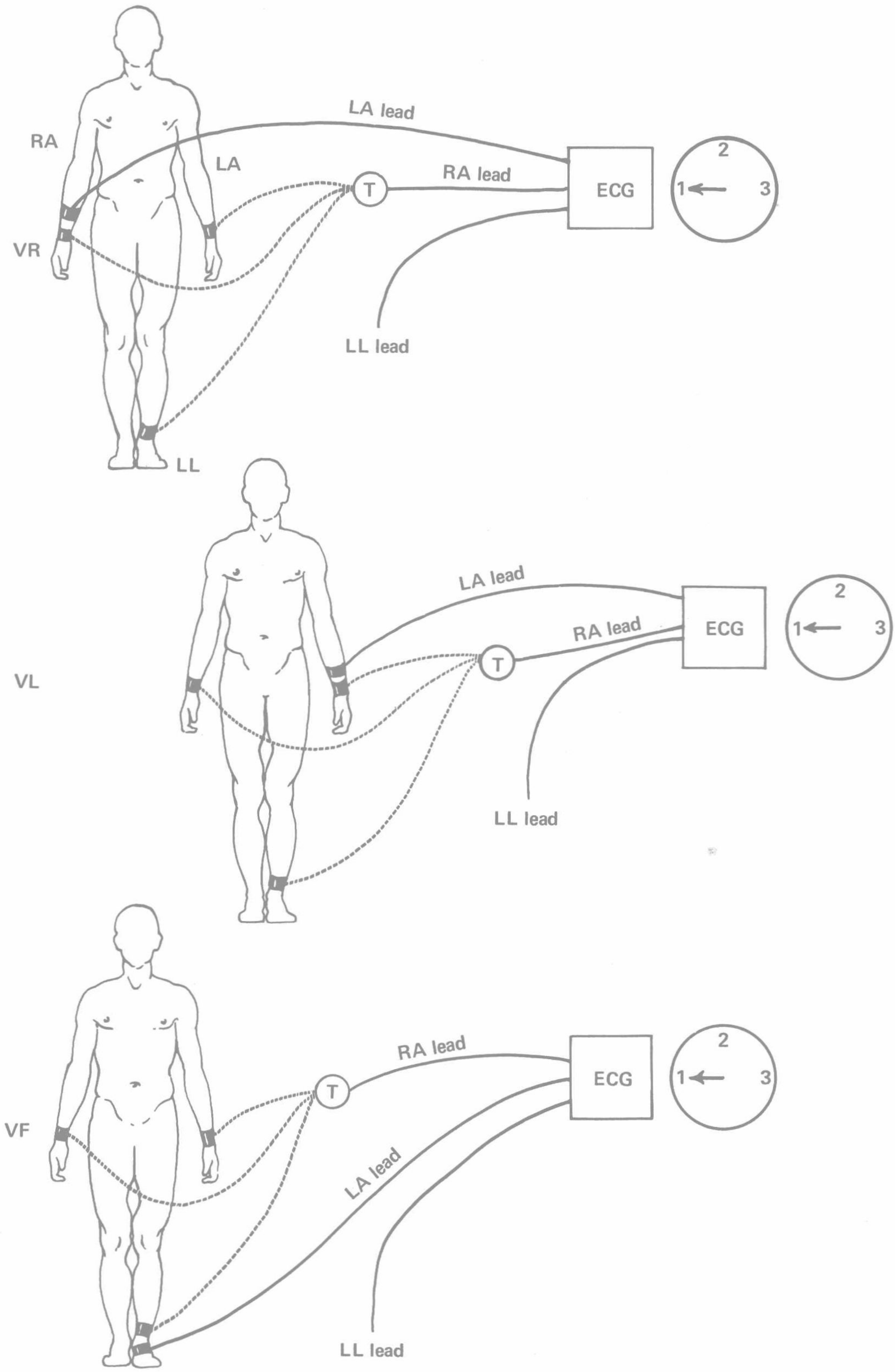


Figure 1–6. Nonaugmented extremity leads.

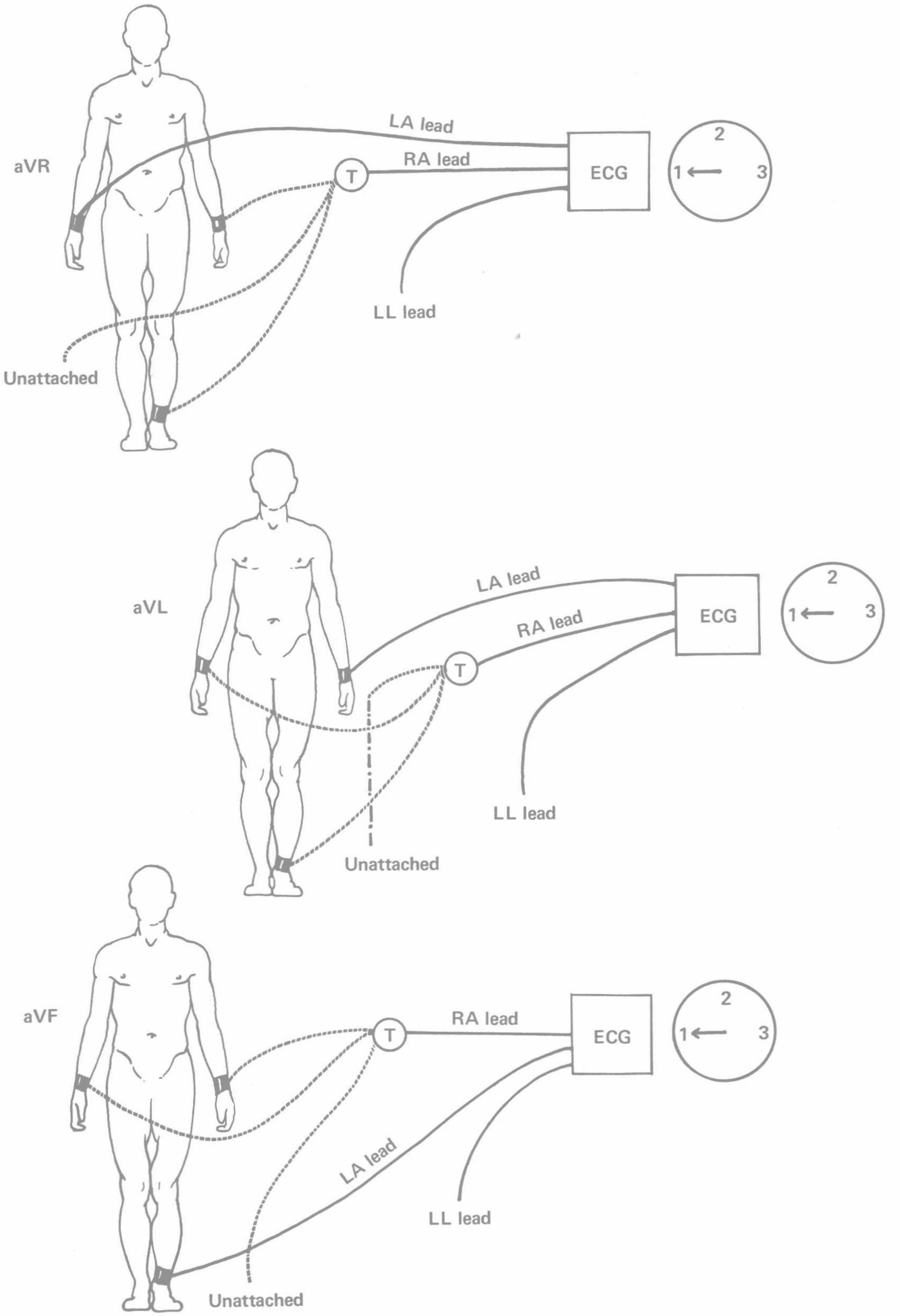


Figure 1–7. Augmented extremity leads.

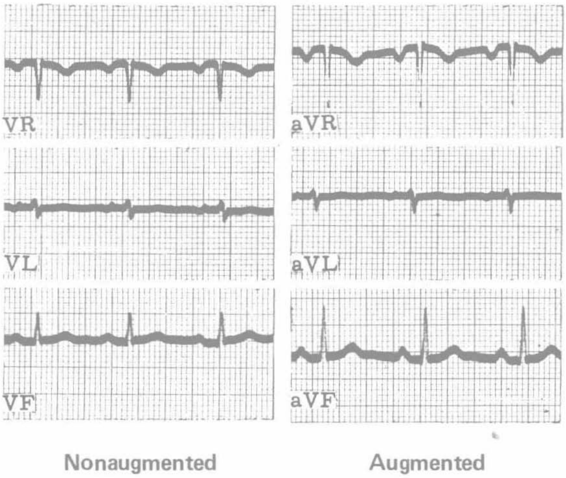


Figure 1–8. Comparison of nonaugmented and augmented extremity leads. All of the above leads are taken on the same individual. Note that the pattern in comparable leads is the same; the only difference is that the augmented extremity leads are of greater voltage (approximately 3/2).

As in the nonaugmented leads, the 3 wires of the indifferent electrode are connected to the 3 extremities (LA, RA, and LL); the central terminal is connected to the RA lead of the machine; the LA lead of the machine becomes the exploring electrode; and the selector dial is set on lead I. (See Fig 1–7.)

(1) To take aVR, the indifferent lead to the right arm is removed and left unattached, and the LA lead of the machine is attached to the RA electrode.

(2) To take aVL, the indifferent lead to the left arm is removed and left unattached, and the LA lead of the machine is attached to the LA electrode. (Of course, the indifferent electrode removed from the right arm in taking aVR has been replaced.)

(3) To take aVF, the indifferent lead to the left leg is removed and left unattached, and the LA lead of the machine is attached to the LL electrode.

UNIPOLAR PRECORDIAL (CHEST) LEADS

These are obtained by turning the selector to V on the dial or, in the older machines, by using the following directions:

The indifferent electrode leads remain connected to the 3 extremities. The central terminal is attached to the RA lead of the machine. The selector dial is set on lead I. The LA lead of the machine is attached to an electrode that can be applied to the desired chest positions, producing multiple unipolar chest leads. (See Fig 1–11.) This results in a V lead. The common precordial positions used (as recommended by the American Heart Association) are as follows:

V_1: Fourth intercostal space at the right sternal border.
V_2: Fourth intercostal space at the left sternal border.
V_3: Equidistant between V_2 and V_4.
V_4: Fifth intercostal space in the left midclavicular line. All subsequent leads (V_{5-9}) are taken in the same horizontal plane as V_4.
V_5: Anterior axillary line.
V_6: Midaxillary line.
V_7: Posterior axillary line.
V_8: Posterior scapular line.
V_9: Left border of the spine.
V_{3R-9R}: Taken on the right side of the chest in the same location as the left-sided leads V_{3-9}. V_{2R} is therefore the same as V_1.
$3V_{1-9}$: Taken one interspace higher than V_{1-9}; these are the third interspace leads. The same terminology can be applied to leads taken in other interspaces, eg, $2V_{1-9}$, $6V_{1-9}$, etc.
V_{3R-9R}: Right precordial leads taken one interspace higher than V_{3R-9R}.
VE: Taken over the ensiform cartilage.

The usual routine ECG consists of 12 leads: I, II, III; aVR, aVL, aVF; and V_{1-6}.

MONITOR LEADS

Although it is possible to use any lead (or multiple simultaneous leads if equipment is available) in a specialized area such as a coronary care unit, it is more common to use a modified bipolar chest lead. The positive electrode is placed in the usual V_1 position and the negative electrode near the left shoulder. A third electrode is placed at a more remote area of the chest and serves as a ground. The recording will be similar to V_1 (a modified CL_1). This lead is of major value in rhythm evaluation. However, if it is deemed necessary to monitor the patient for ST–T changes due to ischemia or potassium abnormalities, it is advisable to place the positive electrode in the V_4 or V_5 position.

UNIPOLAR ESOPHAGEAL LEADS

Esophageal leads can be taken by attaching an esophageal lead to the V (chest) lead of the modern machine or the left arm lead of the improvised machine, using the indifferent electrode.

Esophageal leads are taken from within the esophagus. A nasal catheter through which is threaded a wire with an electrode attached to its tip can be passed through the nares into the esophagus. Using this as one terminal and the zero potential as the other terminal, a unipolar esophageal lead can be obtained. This is designated an E lead. The nomenclature of the lead is derived from the distance in centimeters from the tip of

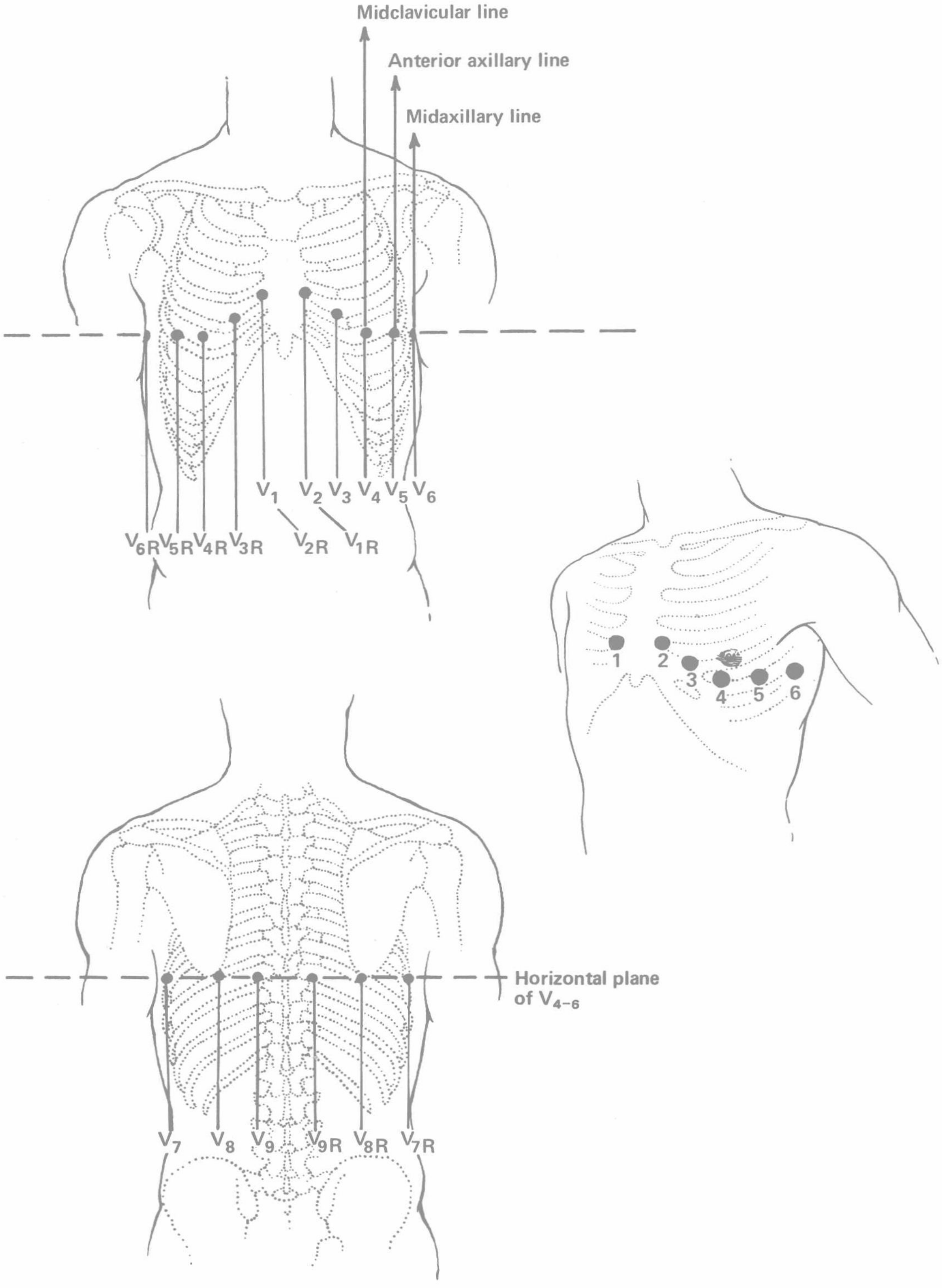
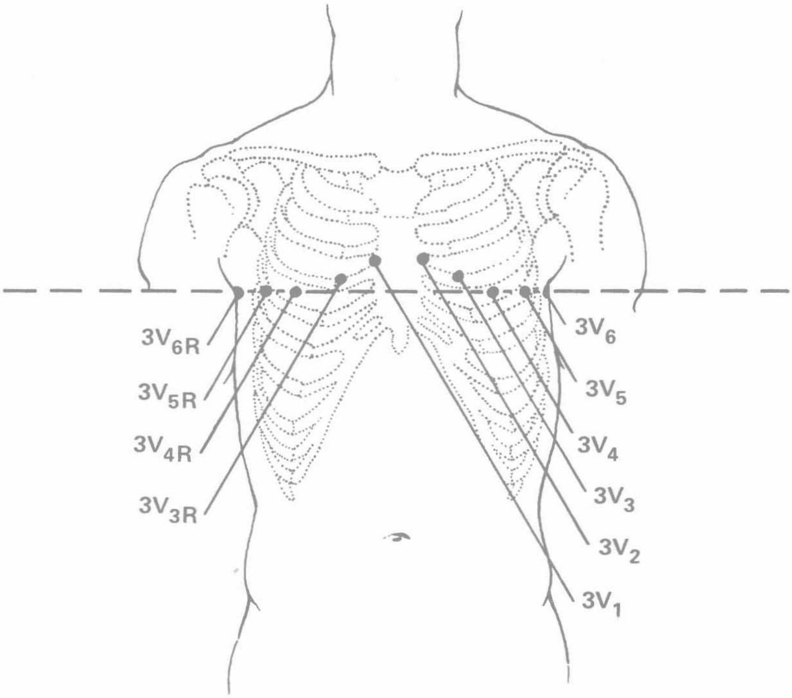


Figure 1–9. Locations of unipolar precordial leads.



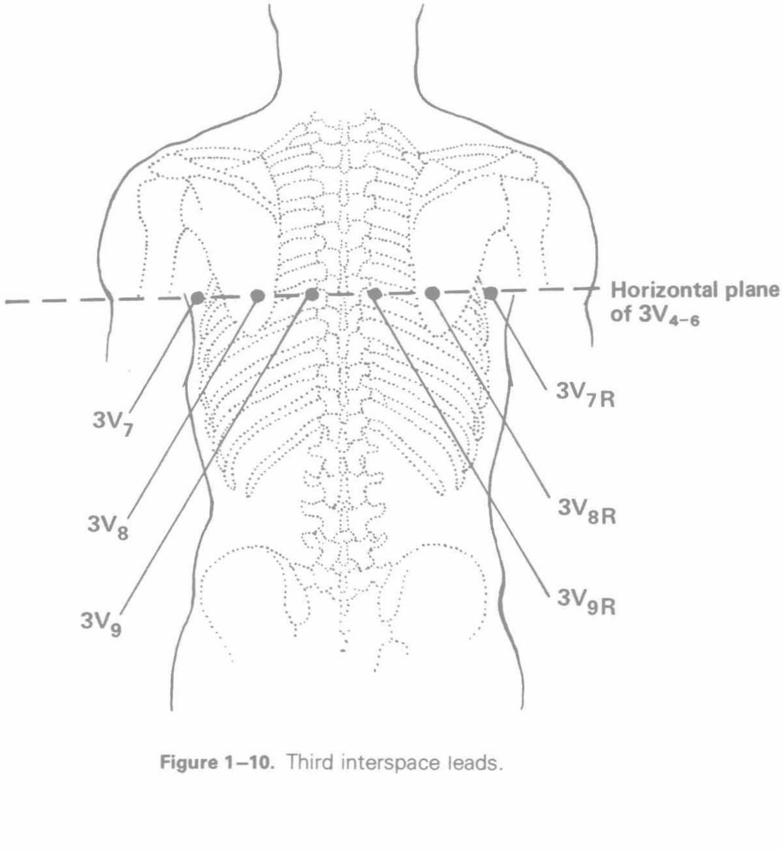


Figure 1–10. Third interspace leads.

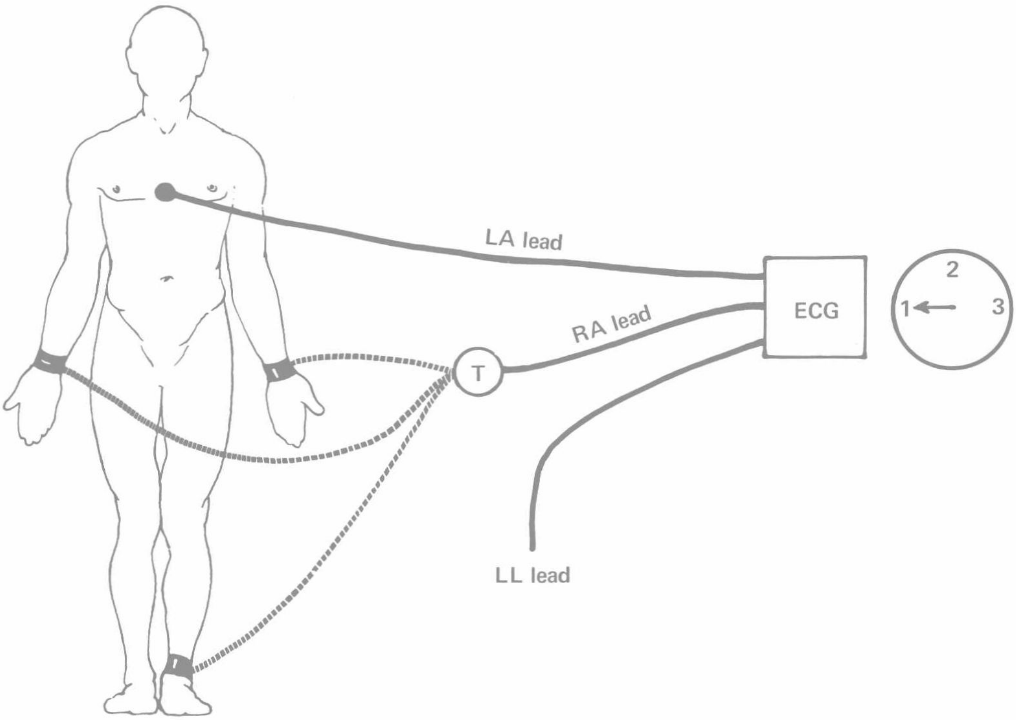


Figure 1–11. Unipolar chest leads.

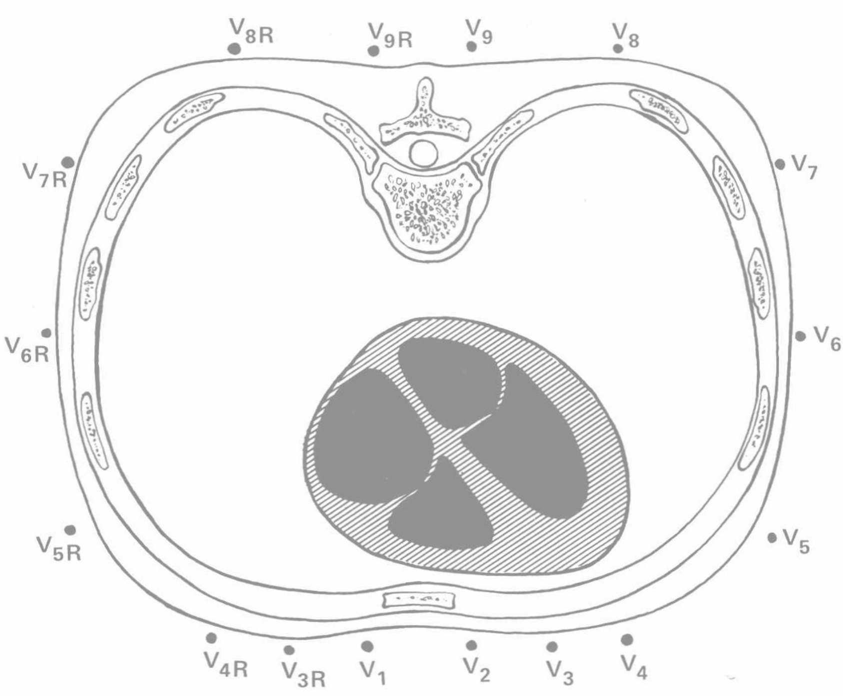


Figure 1–12. Transverse section of thorax illustrating position of the unipolar chest leads.