The last report of the Committee on Electrocardiography of the American Heart Association appeared in 1954. It was concerned with instrumentation, techniques, and nomenclature of electrocardiographic and vectorcardiographic leads. Its objective was to bring about, so far as possible, some standardization which would ensure uniformity in clinical application without discouraging or restricting continued investigation where indicated.

In the 12 years since its appearance, the report seems to have accomplished its purpose so far as conventional scalar leads are concerned. Electrocardiographic practice has become quite uniform throughout the world. The comfortable feeling of this orderly and standardized state goes back to 1938 when the first efforts to establish uniformity in electrocardiographic practice began. Rapid progress in recent years has resulted in the not unexpected expression of dissatisfaction with the recommendations as they stand now. The Committee, therefore, considered the time appropriate to review the previous report and to make new recommendations as indicated.

Several areas of endeavor appeared to need particular attention. With the advent of magnetic tape, analog-to-digital converters, and a variety of programs for analysis of electrocardiographic data by computer, it was clearly propitious to review the entire, intricate problem of instrumentation in present-day electrocardiography. The Committee felt that, because of technical advances in recording devices and methods, advice in this area should be obtained from experts.
who are, in addition, familiar with the practical problems of electrocardiography. Accordingly a Subcommittee on Instrumentation was appointed, composed of physicians and biomedical engineers. In the present report, the greatly expanded section on INSTRUMENTS is almost exclusively the work of this productive Subcommittee.

An effort has been made to define recommended specifications of recorders as precisely as possible and to indicate ranges of latitude when indicated. In order to ensure better maintenance of specified performance characteristics, a description of a relatively simple device for testing direct-writing electrocardiographs has been included and is recommended for use at regular intervals. The tests can be performed by a trained electrocardiographic technician. In addition it is recommended that recorders be checked regularly by engineering personnel for a more thorough performance evaluation.

No attempt was made to give detailed justification for each recommendation regarding instruments in this short report. It is planned to include these in a more detailed report to follow.

The major portion of the recommendations on instruments deals with direct-writing electrocardiographs which are the most convenient and most widely used at this time. However, such recorders possess significant limitations in fidelity of data reproduction, particularly in the frequency range. Recommended specifications for direct-writing electrocardiographs represent minimum requirements. Whenever possible a broader frequency bandwidth than they provide is desirable, particularly in electrocardiographic investigations. Recommendations for electrocardiographic preamplifiers to be used for wide-band recording have, therefore, been made also. Such preamplifiers should be incorporated in vectorcardiographs and in any other electrocardiographic recording apparatus not limited in frequency response by a direct-writing mechanism.

As a consequence of the increasing interest in automatic processing of electrocardiographic data, specifications for magnetic tape recorders and analog-to-digital data converters have become necessary. Recommendations regarding these have been included in the present report. Considerable progress may be anticipated in this rapidly changing field of technology. This portion of the "Recommendations" should be considered as a guideline of a general nature, and users are urged to obtain most recent information concerning equipment capabilities.

That there is redundant electrocardiographic information in the usually recorded 12 leads4 is generally agreed. However, when the suggestion is made to the clinician that the number of leads he is using now is excessive, resistance to change is encountered which results probably from the combination of long-ingrained habit and the inadequacy of clinico-pathological and other correlations with orthogonal leads.

The problem of reducing the number of leads for clinical usage is inextricably involved with the problem of selecting a standard reference frame for recording vectorcardiograms. In each instance the immediate objective of leading from the surface of the body is to get a record of the true orthogonal components—x, y, and z—of the heart regarded as an electrical generator. Whether this record should be in a scalar, vector, or digital form will probably be ultimately determined by practical considerations such as convenience, speed, accuracy, and personal preference. The acquisition of the data on magnetic tape makes reproduction in any form desired a possibility limited only by the amount and cost of the data-handling equipment.

The numerous systems for vectorcardiographic recording can be divided into two classes: the uncorrected and the corrected. In the former, electrode placements for acquiring orthogonal components are based on anatomic considerations. In the latter the placements are based on electrical considerations arising out of the concepts of the lead vector5 and of image space.6 In these systems the lead, regarded as a vector, is adjusted in length and direction for acquisition of the
desired lead orthogonality; hence they are designated “corrected.”

Although the corrected leads are based on the assumption that the cardiac generator behaves as a dipolar source of electrical energy, and indeed are usually designed to ignore multipolar components, nevertheless, it is the opinion of the Committee that they are founded on firm physical principles. In contrast, uncorrected leads, designed for the most part before the lead vector concept or the closely related lead field concept was known to electrocardiographers, are based on erroneous principles relative to the distribution of electrical currents in volume conductors as now understood. Although these uncorrected systems were admirable beginnings in a new modality at the time of their origin, were and continue to be of considerable practical value to their adherents, and were most useful in laying the groundwork for further vectorcardiographic investigation, they are not recommended for general use for the reasons given.

The Committee deliberated on which of the several corrected systems thus far described should be recommended. In making such a choice, consideration must be given to such matters as the present general or restricted use of the method; the practicality of it in terms of the number of electrodes and corrective resistors, especially as related to the input impedance of recorders; reproducibility of results; and possibly the similarity of the recommended orthogonal leads to scalar leads now used in clinical medicine so that the infinite amount of information collected with the latter and clinically correlated over the years will not be entirely wasted. The conclusion reached was that no single one of the corrected systems could be designated at this time, but that a more or less natural selection based on the above considerations would occur in the future.

In anticipation of the circumstance that eventually the same leads will be used for electrocardiography and vectorcardiography, the Committee has changed the outline of its recommendations compared to the report of 1954. Rather than treat electrocardiographic and vectorcardiographic leads as entities in themselves with a consideration of instruments, techniques, and nomenclature under each, the report is simply divided into INSTRUMENTS and LEADS with appropriate subdivisions. Further, since most of the previously reported recommendations on techniques and nomenclature are available at two permanent sources, only those aspects which have needed amplification or modification are considered in the present report.

Instruments

A. Direct-Writing Electrocardiographs

1. System performance, linearity, and distortion

The deviation of the recorded output from an exact linear representation of the input signal shall not exceed 5% of the peak-to-peak output for amplitudes between 5 and 50 mm. For peak-to-peak amplitudes below 5 mm, this deviation shall not exceed 0.25 mm. The input signal may be comprised of frequency components between 0.05 and 100 Hz in any combination. For signals containing frequency components above 50 Hz, the peak-to-peak output amplitudes contributed by these components need be no greater than 5 mm to meet this performance requirement.

2. Input range

The instrument shall meet specifications with input amplitudes up to 10 millivolts peak-to-peak and shall function accurately for any input signal and electrical or mechanical offset so long as the ideal response will require the writing point to remain on the ruled portion of the recording chart.

3. Input impedance and current

In each position of the lead switch the magnitude of the input impedance over the working frequency range shall be no less than 500,000 ohms between any single patient electrode and ground. This measurement is to be made with all patient electrodes grounded except the one under consideration.
The instrument shall not cause currents greater than 1.0 microampere to flow in the circuits to the patient.

Because of offset potentials which may exist at the electrodes, the instrument shall be capable of meeting all specifications when differential offset voltages up to 100 millivolts and common mode offset voltages up to 200 millivolts are present.

4. Central terminal

The magnitude of the deflections in all leads, including the augmented leads, referred to the central terminal,[4] must not deviate from their correct values by more than an additional 2% from the allowable deviations specified in paragraph A1.*

5. Gain

The gain is to be adjustable from the panel of the instrument in three clearly labeled fixed steps, having the following values:

- 10 mm per millivolt
- 5 mm per millivolt
- 20 mm per millivolt

Any continuous or vernier gain adjustment should be available as a restricted access control to be operated, for example, by screwdriver. Since the need to use this adjustment may often be caused by deterioration of the calibrating (standardizing) signal (par. A13), a note to this effect should be placed near this control.

6. Stability of gain and base line

To verify stability of gain and base line, the following test may be performed: Connect the right leg (RL) terminal, in each instance through a resistor of 20,000 ohms, to the terminals of the right arm (RA), the left arm (LA), the left leg (LL), and the chest.

a. With the lead selector switch on Lead I and the sensitivity switch on 20 mm per millivolt, turn the machine on after it has not been used for at least 1 hour. After 3 minutes, center the trace. During the next 12 minutes the base line should not drift more than 10 mm. During the following 45 minutes, the base line should not drift more than an additional 2 mm. After 1 hour, turn the lead selector switch through all positions. In each case the base-line level after the reset button has been pressed should not shift by more than 1 mm from its value in Lead I.

b. With the lead selector switch on Lead I and the sensitivity switch on 20 mm per millivolt, turn the machine on after it has not been used at least 1 hour. After 3 minutes, center the base line. Press the 1 millivolt calibration button. The deflection of approximately 20 mm should differ by less than 1 mm from the deflection measured after 1 hour.

c. Turn the instrument off. Turn it on again 1 hour later. The deflection measured in the Lead I position after

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*Circulation, Volume XXXV, March 1967
Recommended minimum frequency response of direct-writing electrocardiographs. On the ordinate the ratio between input and output is indicated in per cent. The response of the recorder shall be between the upper and lower limits as indicated by the solid lines in the figure.

1 hour’s warm-up should differ by less than 0.5 mm from that measured in step b.

7. Overload
There shall be no damage to the instrument when it is subjected to 1.0 volt at any frequency from 47 to 63 Hz applied for 2 seconds to the input terminals with the controls set at any sensitivity or lead position.

8. Frequency response (fig. 1)*
In addition to the linearity and distortion requirements specified in paragraph A1, the following design characteristics are acceptable with constant amplitude sinusoidal input signals:

a. From 0.14 to 50 Hz, the response shall be flat to within ±6% (±0.5 dB). The response down to 0.05 Hz shall not be reduced by more than 30% (-3 dB) from the response at 0.14 Hz. This requirement corresponds to a “time constant” of at least 3.2 seconds, where “time constant” refers to the time required for a direct current step input (such as the calibration voltage) to decay to 36.8% of its original magnitude.

b. With an amplitude response of 5 mm peak to peak at 50 Hz, the response to constant amplitude sinusoidal input signals up to 100 Hz shall not be reduced by more than 30% (-3 dB), leaving an amplitude of at least 3.5 mm at 100 Hz.

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12. The response shall at no frequency exceed the restraints specified for the range of 0.14 to 50 Hz.

9. Common mode rejection

For each position of the lead switch with the recorder gain set at 10 mm per millivolt, and with all active electrode leads connected together, a potential difference of 100 millivolts peak-to-peak applied between them and the right leg lead shall cause no more than 1.0 mm peak-to-peak deflection for frequencies from 45 to 65 Hz. In a like manner the application of 10 millivolts shall cause no more than 1.0 mm peak-to-peak deflection at any frequency. This specification must be met when a resistance of 5,000 ohms is placed in series with any one electrode lead.

These requirements correspond to a common mode rejection of 1,000:1 at frequencies between 45 and 65 Hz, and 100:1 at any other frequency.

10. Noise level

Upon simulating a subject by means of completely shielded resistors of 25,000 ohms placed between each patient lead and ground, the output noise, with the recorder calibrated to 10 mm per millivolt, shall not exceed the equivalent of 0.1 mm root mean square in any position of the lead switch (10 microvolts root mean square referred to the input).

11. Radio frequency interference

Manufacturers are urged to minimize interference from radio and other high frequencies through proper design of circuits, shielding, and filtering in the power supply.

12. Grounding

Line-operated electrocardiographs shall be supplied with a three-terminal, power-line plug.

The existence of multiple connections between a subject and a line-operated electrocardiograph creates the potential hazard of uncomfortable or even lethal electric shock. Protection of the patient and the operator from currents greater than 5 milliamperes must be provided by fuses or circuitry to furnish equal protection under any of the following circumstances present singly or in any combination:

a. When the subject is inadvertently or purposely grounded by connection to a second device.

b. When defective or frayed insulation of the power cord of any transformer, motor, or other line-operated component may make the case containing the electrocardiograph “hot.”

c. When an incorrectly wired, three-wire receptacle is used to energize the electrocardiograph.

d. When an internal short circuit or component failure may occur in the amplifier connected to the patient.

e. When the subject may be wired directly to the instrument case.

Since satisfactory recording in electrically noisy locations may be possible only by connecting the instrument directly to a ground more suitable than can be obtained through the power-line plug, provision for this alternate mode of operation must be made. With or without such a connection, leakage of current back to the power-line ground or to the auxiliary ground for either polarity of the power line, must be less than 50 microamperes.

Currents considerably less than 5 milliamperes in magnitude may cause ventricular fibrillation in a patient when a saline-filled catheter or other externally accessible, artificial conducting connection to the heart is present. The user must be warned of the potential hazard of a line-operated or battery-operated electrocardiograph under these special circumstances since the protection against electrical shock ordinarily afforded by the instrument may be inadequate.

13. Calibration ("standardization")

The standardizing voltage shall be a signal of 1.0 millivolt ±2% with a time

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constant no less than 100 seconds and an output impedance of 1,000 ohms or less, which can be applied continuously to the inputs by a switch on the panel of the instrument. When a multichannel recorder is used, means shall be provided for the simultaneous application of the calibration signal to all channels. The instrument shall be capable of recording this standardizing voltage as follows:

a. Superimposed in series while recording the electrocardiogram from any lead position, and

b. With the patient disconnected from the instrument.

In addition, the standardizing signal shall be available through a suitable connector to provide for checking of its accuracy.

If a battery is used for obtaining the standardizing voltage, the instrument shall be provided with an indicator (a push-to-test control is suggested) to alert the user when the battery needs replacement; for example, battery is no longer capable of supplying the standardizing voltage to the required accuracy.

14. Speed and speed accuracy

A minimum of 2 speeds, 25 mm per second and 50 mm per second, shall be available. Accuracy of speed shall be ±2% when operating from a 60-cycle source.* Time markings at intervals of 1 second ±2% shall be recorded at all speeds at an edge of the time rulings of the recording paper by a device operating independently of the transport mechanism of the recorder.

15. Recording paper

The recording paper shall be ruled with 1.0 mm divisions along both the time and voltage axes. Every fifth division shall be ruled darker than the others. The 1.0 mm divisions shall not deviate by more than ±1% from 1.0 mm in either axis. The ruled divisions shall cover a total of 5 cm in width, and recordings shall be rectilinear.

These dimensional accuracies shall be met throughout a temperature range from 10 C to 50 C and for relative humidities from 10 to 80%.

16. Skew

a. Skew of recording, due to all causes, shall not exceed 0.1 mm of horizontal displacement per 1.0 cm of vertical deflection.

b. In multichannel recording, it is especially important to ensure temporal alignment of traces. Therefore, with the amplifiers for each channel set to the same frequency response limits, all traces shall fall dynamically within a 0.5 mm band of the ideal (zero skew) response at all transport speeds for the entire frequency range of the instrument.

17. Recorded output

The vertical width of the undeflected trace shall not exceed 1.0 mm at any paper transport speed. Both the upstroke and downstroke of the writing device at rates of deflection less than 1,000 mm per second shall leave a visible, continuous trace with sharp edges.

18. Auxiliary output

A jack shall be available for gaining access to the output. The signal at this jack shall have a driving capability of at least 1.0 milliampere for loads of 1,000 ohms or more at ±1.0 volt, full scale. The output impedance shall be less than 100 ohms. The output characteristics shall be the same as specified herein except that the frequency response shall extend to at least 1,000 Hz (1 dB down). This output shall have a dc offset voltage no greater than ±1 volt, which can be centered at zero volts.

No damage shall occur to the instrument when the output is short circuited.

*Accuracy requirements of ±2% have been specified to permit use of synchronous timing devices and synchronously operated paper transports. If such devices are used, they will be unable to meet the accuracy requirement when the line frequency deviates appreciably from 60 cycles; therefore, a note to this effect should be placed on the instrument.
Upon removal of the short circuit, the instrument shall be capable of meeting specifications.

19. Trace reset
A capability for trace reset must be provided by a switch or button on the instrument. After a pulse of 10 millivolts has been applied to the input for 10 seconds at a gain of 20 mm per millivolt, depressing this button shall cause the trace to return to within 1 mm of its initial position within 0.5 second. Releasing the button after it has been depressed for not more than 0.5 second shall result in no more than 1 mm of additional displacement.

20. Power-line variations
For instruments operating at 60 Hz and 120 volts, all specifications shall be met when used in the range of power line voltages from 95 to 135 volts and frequencies from 57 to 63 Hz. A disturbance of ±5 volts in the power line should not cause a deflection greater than that which would be obtained with an input signal of ±50 microvolts.

For battery-powered instruments, an indicator shall be provided to alert the operator when the batteries need replacement or recharging.

21. Temperature and altitude
The instrument shall meet all specifications over the temperature range of 10°C to 50°C, at altitudes from 0 to 3,000 meters above sea level and at relative humidities of 5% to 95%.

22. Electrode impedance
It is desirable that any paste or jelly and electrode combination which is used results in a skin-to-electrode impedance of 5,000 ohms or less, measured at 60 Hz with currents not exceeding 100 microamperes.*

23. Standardization of controls, cables, legends, and recording format
Electrocardiographs meeting this specification shall be equipped with the following controls labeled as shown in quotation marks.

- **“Paper Speed”**
  - Two-position switch
    - “25 mm/s”
    - “50 mm/s”

- **“On-Off”**
  - Two-position switch
    - (Light or flag indicating equipment is on.)

- **“1 mV”**
  - Push button

- **“Lead”**
  - Multiposition switch
    - “I,” “II,” “III,” “aVR,” “aVL,” “aVF,” “V”

- **“Center”**
  - Potentiometer

- **“Reset”**
  - Push button or switch

- **“Gain vernier”**
  - This potentiometer shall be a recessed control behind a hinged plate.

- **“Sensitivity”**
  - Three-position switch
    - “5 mm/mV,”
    - “10 mm/mV,”
    - “20 mm/mV”

The following cable legends and colors shall be used:

- **“RA”**
  - Right arm
  - white

- **“LA”**
  - Left arm
  - black

- **“LL”**
  - Left leg
  - red

- **“RL”**
  - Right leg
  - green

- **“C”**
  - Chest
  - brown

24. Testing device for direct-writing electrocardiographs
Random tests have indicated that of various types of direct-writing electrocardiographs in common clinical use, a conventional input circuitry, e.g. buffer amplifiers for each active electrode.

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relatively large number failed to meet the American Heart Association's performance recommendations of 1954. Since deterioration of the electrical characteristics of an instrument is not readily apparent from examination of a standardization pulse or a clinical record, a simple device for testing electrocardiographs is advocated. The testing system, which may be an accessory, or be self-contained within the electrocardiograph, employs a switch, seven resistors, and a capacitor (fig. 2A and B). By serially advancing the switch and depressing the calibration button, the low-frequency response, linearity, high-frequency response,* input impedance, and common

Figure 2
Suggested device for checking periodically the low and high-frequency response, linearity, and input impedance and common mode rejection of direct-writing electrocardiographs. The circuit of the testing device (A) is shown on the left above with the test signals, tests, and required readings in the respective columns below (B).

<table>
<thead>
<tr>
<th>SWITCH POSITION</th>
<th>TEST SIGNAL</th>
<th>TESTS</th>
<th>READING</th>
</tr>
</thead>
<tbody>
<tr>
<td>0. 0.</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>1-mv step to chest lead</td>
<td>Low frequency response (time constant)</td>
<td>When calibrate button is held down, the time for a 10 mm/mv signal to decay to 3 mm should be equal or longer than 3.2 sec.</td>
</tr>
<tr>
<td>2.</td>
<td>2-mv step to chest lead</td>
<td>Linearity</td>
<td>Upward deflection of 20 mm ± 0.5 mm</td>
</tr>
<tr>
<td>3.</td>
<td>2-mv step to central terminal</td>
<td>Linearity</td>
<td>Downward deflection of 20 mm ± 0.5 mm</td>
</tr>
<tr>
<td>4.</td>
<td>2 mv</td>
<td>High frequency response</td>
<td>Deflection should be equal to or larger than 5 mm</td>
</tr>
<tr>
<td>5.</td>
<td>10 mv step to chest lead through 10 kΩ resistor and to central terminal through 5 kΩ</td>
<td>Input impedance and common mode rejection ratio</td>
<td>Deflection should be less than 1 mm</td>
</tr>
</tbody>
</table>

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mode rejection can be evaluated. The result of each test can be read as an amplitude of the deflection of the stylus. The one exception is the test of low-frequency response which is evaluated in terms of the time required for a 10 mm per millivolt signal to decay to 3 mm.

Although the foregoing system will permit regular testing to be done easily by an electrocardiographic technician, it is not intended that such tests be regarded as equivalent to a complete performance evaluation necessary to satisfy all recommendations in this report.

B. Recommendations for Electrocardiographic Preamplifiers for Use with Recording Devices Other than Direct-Writers

1. System performance, linearity, and distortion

The deviation of the output signal from an exact linear representation of the input signal shall not exceed 1% of the peak-to-peak output amplitude for amplitudes between 2 and 20 volts. For peak-to-peak output amplitudes below 2 volts, this deviation shall not exceed 0.02 volt. The input signal may be comprised of frequency components between 0.05 and 2,500 Hz in any combination.

2. Gain

The gain is to be adjustable in fixed steps between 200 and 2,000. Any continuous or vernier gain adjustment shall be available as a recessed control for adjustment by screwdriver or similar device. Gain is defined from the single-ended output (or one of the two sides of a double-ended output) to the differential input.

3. Frequency response

In addition to the linearity and distortion requirements specified in paragraph B1, the following design characteristics are acceptable with constant amplitude sinusoidal input signals:

From 0.14 to 950 Hz, the response shall be flat to within ±0.5% (±0.05 dB). The response from 2,500 Hz down to 0.05 Hz shall not be reduced by more than 30% (−3 dB). At no frequency shall the response exceed the restraints specified for the 0.14 to 950 Hz range.

Provisions shall be made on the control panel for lowering the high-frequency cutoff in several steps down to 100 Hz.

4. Common mode rejection

With the amplifier set at a gain of 1,000 and the input leads connected together, a potential difference of 100 millivolts peak-to-peak applied between them and the input signal reference shall cause no more than 100 millivolts of peak-to-peak potential difference at the amplifier output at any frequency. This specification must be met when a resistance of 5,000 ohms is inserted in series with either of the input leads. This requirement corresponds to a common mode rejection ratio of 1,000:1.

5. Noise level

Upon simulating the subject with completely shielded resistors of 25,000 ohms between either or both input terminals and ground, the equivalent input noise at any gain shall be less than 10 microvolts root mean square. Performance characteristics shall be maintained with balanced source impedances up to 100,000 ohms.

6. Calibration ("standardization")

A calibration signal shall be provided for insertion into the input as described for direct-writers (par. A13). When several preamplifiers are being used simultaneously for multiple leads, means shall be provided for simultaneous application of the calibration signal to all preamplifiers. A separate input connector for receiving this signal shall be provided on the instrument.

7. Output

The output shall have a driving capability of 10 milliamperes into loads of 1,000 ohms or greater and shall have an internal impedance of less than 100 ohms. Means should be provided to
center the output voltage at approximately zero volts.

8. Reset of dc output level
   A capability for reset of the dc output level must be provided by a switch or button on the instrument. Pressing this button after a signal of 10 millivolts has been applied to the input for 10 seconds shall return the output to within 0.1 volt of its initial position within 0.5 second or less, and releasing the button shall result in no more than 0.1 volt additional displacement.

9. Differential input impedance and current
   The differential input impedance shall be greater than 20 megohms, and the common mode input impedance shall be greater than 200 megohms. The impedance of each input to signal reference must be balanced to within 1%.

   When the instrument is properly connected to the patient, it shall not cause currents greater than 1.0 microampere to flow in the circuits to the patient.

10. Weighting networks
    When a central terminal, corrective networks for orthogonal leads, or other lead systems requiring weighting resistors are used, consideration must be given to the choice of resistor value as noted in the section pertaining to direct-writing instruments (par. A4 and footnote).

11. Recommendations for input range, gain and base-line stability, overload, grounding, short circuit protection, radio-frequency interference, and allowable variations of power, temperature, and altitude shall be followed as described above for direct-writers. Any reference in these paragraphs to output deflection of the writing device should be interpreted as voltage output with an amplifier gain of 2,000 corresponding to the direct-writer gain of 20 mm per millivolt.

C. Vectorcardiographs

1. Frequency response
   Recommendations for electrocardiographic preamplifiers for use with recording devices other than direct-writers (pars. B1 to 11) shall be followed. In order to facilitate display of P and T loops at high gain, provisions for recording with low-pass filters down to 200 Hz shall be added. These should be available through a switching device with clearly labeled steps.

2. Calibration and phase coherence
   For calibration, plane projections and component leads of each plane should be clearly identified. Since this can be accomplished in various ways, only one of many possible procedures will be described here to illustrate the principles involved.

   The calibration signals may be linearly rising ramp signals of 1 millivolt amplitude, successively applied to x, y, and z amplifiers, each with appropriate positive sense. Application of brightness modulation of the cathode ray oscilloscope beam will serve to identify individual channels by characteristic patterns as shown below:

   ![Diagram of Vectorcardiograph](https://via.placeholder.com/150)

   **X**

   **Y**

   Increased brightness area half way up ramp for Lead Y

   **Z**

   Increased brightness 1/3 and 2/3 way up ramp for Lead Z

   By simultaneous application of one ramp signal to all inputs, phase coherence between channels, a pair at a time for each projection plane (xy, xz, zy), may be checked. Perfect phase coherence will result in a straight-line display at an angle of 45° to the horizontal. The deviation from 45° is an indication of the lack of phase coherence between the channels. Using a ramp rate of 0.05 millivolt per millisecond, the straight-line display should be 45° ± 3°.
3. Time marking

A sawtooth pattern of brightness should be used to indicate the direction of rotation of vector loops by teardrop-shaped dots with the blunt edge leading. Intervals should be available in multiples of 200 per second (for example, 200, 400, 600, 800, 1,000 per second).

Provisions shall be made to inactivate the timing device temporarily should this be necessary in order to record high-frequency components of vector loops.

4. Instrumentation relative to the leads used

Vectorcardiographs should be provided with either a simple switch or plug-in device to facilitate transfer from one lead system to another. Easily exchangeable modules will allow use not only of currently available reference frames but also of their successors without significant modification of the equipment. The component weighting resistors of corrected lead systems should be readily accessible and clearly labeled to facilitate periodic recheck of their values. This feature is also desirable because the values of the resistors may have to be increased from presently accepted ones in order to meet the input impedance recommendations described above (pars. A3 and A4).

5. Certain of the recommendations made for direct-writers and preamplifiers are also recommended for vectorcardiographs. These are covered in paragraphs B1 to 5 and 7 to 11.

D. Magnetic Tape Recording of the Electrocardiogram

In order to assure comparability of tape-recorded data, the instrumentation must meet certain minimum requirements. Furthermore, for faithful reproduction of these data the input specifications of data processing equipment, for example, analog-to-digital data converters, must be met.

1. Tape transport electronics

The recording and reproducing electronics must be such that frequencies from zero to over 100 Hz will be reproduced. This requires that systems such as frequency-modulation (FM), pulse-duration modulation or pulse-position modulation, digital recorder, or similar modulation system be used. The FM system is most commonly used in electrocardiography and the recommendations below apply mainly to this type of system.

2. Tape transports

a. In FM systems the family formats of the Inter-Range Instrumentation Group ("IRIG") are desirable. The IRIG standards apply to the following items: tape widths (½ or 1 inch),* tape thickness, track geometry, head and head stack configuration (including head and stack numbering, gap scatter, and individual azimuth alignment), head polarity, tape guidance, tape speeds, and tape speed tolerances, center carrier frequencies and deviations, deviation direction and frequency drift, and band widths.

b. The low or intermediate-band version of the IRIG standards shall be acceptable. These systems shall be capable of reproducing tapes recorded on low-band systems without major equipment modification.

c. It is desirable that reels and hubs be in accordance with the latest issue in effect of Federal Specifications. The capability of handling reels of 10% inches in diameter is desirable.

3. Voltage range of input

The full scale range of input to the tape transport electronics should be standardized to a span of 2 volts and should be capable of extension to a span of 10 volts through the use of an external adjustable control.

* Tape width of ¼ inch is not specified in the IRIG standards. However, if used, the electrical specifications should conform to these standards.
4. Overloading
   In order to avoid error due to overloading at the input, the instrument must be provided with an indicator to disclose when input overvoltage does occur.

5. Output voltage range
   The full scale output voltage of the "reproduce" amplifiers should extend over 10 volts which can be centered at zero volts. They should also be adjustable from the central panel downward to a span of 2 volts in several steps. The instrument must be capable of providing a ratio of output-to-input voltage of one to one.

6. Linearity and distortion
   Zero-based linearity from "record" input to "reproduce" output shall be within ±1% of the full scale output voltage. Harmonic distortion shall meet the IRIG requirements for single-carrier FM systems.

7. Noise
   The signal-to-noise ratio shall meet the IRIG requirement for Single Carrier FM Systems, e.g., the signal-to-noise ratio of a signal of 0.1 of the maximum modulation frequency recorded at full deviation shall be 40 dB minimum.

   If flutter compensation is needed to accomplish this, a statement to this effect shall be conspicuously placed on the instrument.

8. Time displacement error
   The time displacement error between any two channels due to gap scatter, tape skew, and all other causes shall be kept below 100 microseconds at 7½ inches per second.

9. Start-up time
   The time required for the tape transport to reach a stable speed shall be less than 1.0 second. If greater than this, provision shall be made for disabling the recording amplifiers until stable speed is reached.

10. Monitoring while recording
    The capability of monitoring during, as well as after, recording shall be provided. Signal-to-noise ratio, as specified above, shall not be reduced when reproducing either during or after recording.

11. Input impedance
    The recording electronics shall have a minimum input impedance of 40,000 ohms.

12. Output impedance
    The output impedance of the reproducing electronics shall be less than 100 ohms and the output driving capability shall be at least 10 milliamperes when connected into a load of 1,000 ohms.

13. Alignment
    The instrument shall be provided with a built-in capability for checking the frequency alignment of the recording and reproducing electronics with provisions for checking actual frequency deviations.

14. Recording "disable switch"
    The instrument shall be provided with the capability of disabling individual recording channels through switches on the control panel. This will permit erasing or recording of data on selected channels.

15. Magnetic tape
    It is desirable that high quality instrumentation tape with polyester base and with "A" oxide characteristic be used. Tapes conforming to the latest issue in effect of Federal Specifications¹¹ are recommended.

E. Analog-to-Digital Conversion of the Electrocardiogram

For automatic processing of electrocardiographic data, it is necessary to convert the deflections and intervals to digital form for presentation to the computer. Two general types of analog-to-digital conversion systems will accomplish this. First, where there is a need to process and analyze the data in "real time," an on-line system is required. This takes the form of an analog-to-digital converter which receives the electrocardiographic data directly from the subject and passes it on to the digital computer, operating in this regard as a unit of an
integrated system. Second, when delays of minutes, hours, or days are of no consequence, the analog-to-digital converter may be used separately from the digital computer. In this system the converter receives data either directly from the subject or from previously recorded analog tape. Its output is a digital tape with a format compatible with the digital computer which is to analyze the data.

The requirements for the analog-to-digital conversion equipment are somewhat different in each system and will be outlined in separate sections below:

1. On-line converters

a. Input
   (1) The instrument must be capable of accepting electrocardiographic data either directly from a subject or from analog tape.
   (2) The input impedance for each input line must be greater than 10,000 ohms.
   (3) The input must be capable of accepting a full-scale input voltage span of 2 volts which can be centered about zero volts and adjustable in steps to a span of 10 volts.
   (4) When spatial characteristics of the electrocardiogram are to be analyzed, the instrument has to be capable of accepting more than one of the simultaneously recorded electrocardiographic leads (most commonly three). These records when converted shall maintain temporal relationships.

b. Output
   Since the instrument is usually integrated with a digital computer, the output will, by design, be of the proper form on tape or in another form of memory in the computer. However, digital-to-analog conversion should be provided both for visual monitoring and analog recording.

c. Accuracy
   Accuracy shall be no less than ±1.0% (7 bits*).

d. Precision
   Precision, that is, resolution, shall be no less than ±0.2% (9 bits).

e. Sampling rate
   A minimum sampling rate of 500 samples per second shall be provided for each electrocardiographic lead for proper measurement of conventional parameters.
   Computer analysis of high frequency components of the electrocardiogram requires considerably higher sampling rates.

f. Testing
   The instrument shall be provided with a built-in facility for testing accuracy and precision.
   Provisions for periodic verification of other dynamic characteristics are desirable.

g. Visual monitoring
   Provision shall be made for visual monitoring of the input signal.

h. Alarm and checking features
   (1) Provision shall be made for a suitable indication when the input has caused the analog-to-digital converter to reach full scale.
   (2) An indication shall be provided for alerting the operator when a record has been digitized with a parity bit error.
   (3) If a record is improperly digitized, an indication shall be provided from the analog-to-digital conversion equipment or the computer.

2. Off-line converters

a. Output
   The instrument must be capable of

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*"Bit" is a contraction for "binary digit." It is a unit of information equal to the result of a choice between two alternatives (see Glossary).
providing the digital output in a format compatible with the digital computer to be used for data processing.

b. Alarm and checking features

Same as for on-line converters (par. E1h).

c. Other inputs

Provision shall be made for insertion of identification information, such as patient number, date, and so forth, into each record in such a manner that both this information and the digitized electrocardiographic data can be carried on the same record.

d. The following features shall be the same as for on-line converters: input, accuracy, precision, sampling rate, testing, and visual monitoring.

**Leads**

**A. Techniques, Scalar**

1. The techniques described in the previous report\(^1\) for bipolar extremity leads, unipolar extremity leads, unipolar precordial leads, and unipolar esophageal leads are recommended with the following additions and modifications:

   a. Unipolar endocardial leads

   The exploring or endocardial electrode may be a small cylinder, approximately 2 mm by 3 mm, of non-corrosive metal placed at the end of a standard solid or hollow cardiac catheter. It is connected by insulated wire within the catheter to a clip or jack at its proximal end to which an input terminal of the recording device may be attached. As a substitute, a polyethylene catheter containing a conducting solution may be used. A lead-wire from the input may be clipped to an occluded hypodermic needle in contact with the solution at the proximal end of the catheter (see **Instruments**, pars. A3, A4, and footnote).

   Placement of the endocardial electrode is done most accurately and safely with the aid of the image-intensified fluoroscope. However, in patients too ill to be moved, the polyethylene catheter may be inserted preferably via a saphenous vein, and entry of the tip into the right atrium or right ventricle may be determined by the voltage and configuration of the continuously monitored endocardial or intravascular electrocardiogram.

   The central terminal\(^4\) is to be used as the indifferent electrode as for other unipolar leads. Response of the electrocardiograph to the introduction of 1.0 millivolt must usually be reduced from the customary 1.0 cm because of the increased magnitude of intracardiac deflections. The calibration should be recorded on each lead made.

   The leads obtained are designated by the symbol V followed by the upper case subscript IVC, SVC, RA, RV, or PA, depending upon whether the recording is from the inferior or superior vena cava, right atrium, right ventricle, or pulmonary artery, e.g., \(V_{IVC}, V_{SVC}, V_{RA}, V_{RV}, V_{PA}\).

   b. With high impedance amplifiers in electrocardiographs the requirement of a resistance of 5,000 ohms in each of the arms of the central terminal\(^4\) is inadequate and should be increased by an approximate factor of 60 to 100 (see **Instruments**, pars. A3, A4, and footnote).

**B. Techniques, Vector**

1. Polarity of leads

The previous principles laid down relative to the use of unipolar leads for vectorcardiographic recording still apply.\(^1\) With regard to bipolar leading, no problems have been apparent in making the proper connection of the input terminals to the electrodes involved either in the recording of the frontal or transverse vectorcardiogram or of the transverse (x) or longitudinal (y) axial leads.
Custom and increasing knowledge of the excitatory process have long dictated that, when the right arm is electronegative with respect to the left, or when the cephalic electrode is electronegative with respect to the caudal, the recorded deflection shall be upright in the corresponding bipolar scalar record. Observing these same polarity conventions and making connections to the oscilloscopic deflection plates by assuming that the screen is the plane of the body being studied, with the observer facing it, the recorded frontal planar loop will have an orientation as it is known to have in the body.

In the case of the sagittal lead and of the planar vectorcardiograms of which it is a component (transverse or xz, and sagittal or zy), conventions are not so firmly established. The problem is complicated by the fact that the mean direction of excitation of the ventricles in normal subjects is usually backward in these planes. To incorporate the sagittal component with the proper polarity into a sagittal or transverse vectorcardiogram, therefore, the input terminals of the scalar recorder must be connected in such a way that the lead reflects the true sagittal direction of the electromotive force in the body. Such connections—negative terminal anterior, positive terminal posterior—will result in transverse and sagittal vectorcardiograms with the same relative positions to orthogonal axes on the oscilloscopic screen as they have to such axes in the body.

But if the scalar sagittal lead is connected in the manner indicated to an ordinary electrocardiograph, the scalar record will have the approximate appearance, depending on the system used, of an average unipolar precordial lead inscribed upside down. The reason is that unipolar thoracic leads have customarily been obtained only from the front of the thorax; the polarity in the bipolar sagittal lead necessary for recording a properly oriented vectorcardiogram results in a scalar lead simulating what would be obtained with a unipolar electrode placed on the back of the thorax.

Although simulation of previously recorded experience would facilitate clinical usage and interpretation, switching the polarity of a lead depending on its scalar or vector use would be undesirable. In the interest of a consistent view of the principal spatial force which normally is downward, leftward, and backward, it is recommended that the sagittal component of the vectorcardiogram, when recorded as a scalar lead, be inscribed with the input terminals of the recorder attached to the body in such a way that electropositivity of the posterior electrode results in an upward deflection in the finished record. The bipolar connections to the sagittal lead for scalar recording are then the same as those used for oscilloscopic recording of the sagittal plane viewed from the left.

2. Selection of views

The frontal view and the transverse view from above seem to have been generally accepted as standard although there would be one advantage to viewing the latter from below (see par. D3 below). The sagittal display has been published as viewed from both the right side (right sagittal) and left side (left sagittal) with almost equal frequency, and with the inevitable difficulty of comparing one study with another. Cogent arguments have been put forth for the use of either view. However, in keeping with the recommended polarity of the scalar sagittal lead, the sagittal planar vectorcardiogram viewed from the left is preferred.

C. Nomenclature, Scalar

The nomenclature previously outlined is again recommended. It has been noted that the suggestion for labeling the atrial T wave as \( T_a \) has not been generally accepted over the older nomenclature, \( T_a \). The
D. Nomenclature, Vector

1. It is recommended that the components of the vectorcardiogram be designated as "loops" or "forms" and that the letters P, T, QRS, T, and U be used to describe the five forms ascribable to the same electrical processes which account for the similarly designated deflections in the scalar electrocardiogram.

The symbol or abbreviation for the word, vectorcardiogram, is VCG.

2. Recommendations previously made with respect to designation of axes (x, y, z—transverse, longitudinal, sagittal) and planes (xy, yz, zx—frontal, sagittal, transverse) are continued. Neither the more commonly used term, "horizontal," or the rarely used term, "superior," in referring to the transverse axis or plane, though acceptable, is preferred because the axis or plane thus designated is only horizontal or superior when the patient is standing or sitting. Similar reasoning lies behind the preference for longitudinal to vertical when referring to the long axis of the body.

3. A simple standard method for indicating the direction of the vector in three planes is desirable. In the frontal plane, custom, since Einthoven, is quite fixed. Regarding

*The order of the letters has been reversed compared to the earlier report in order to indicate the proper reference axis as z in the sagittal plane.12

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that a change is not likely to be accepted. Therefore, in the display of the transverse plane viewed from above, the upper and lower halves are reversed in sign as contrasted to the frontal and left sagittal views. Angles written in a counterclockwise direction beginning at the left end of the x-axis have a positive value from 0° to +180° and those written in a clockwise manner have a value from 0° to −180°. It is recommended that this angle, as in a spherical coordinate system (see below), be designated "H°."*

If the spherical coordinate system is used for designating the location and magnitude of spatial vectors, it is recommended that the symbols for elevation (latitude), azimuth (longitude), and magnitude be V°, H°, and M†, respectively. Azimuth is the angle between the horizontal (transverse) projection of a spatial vector and the left half of the x-axis and it is identical with H° as defined for the transverse plane above. Anterior angles (0° to −180°) are regarded as negative, and posterior angles (0° to +180°) as positive. Elevation is the angle between the spatial vector and the transverse plane. Inferior angles are positive (0° to +90°).

4. Communications would be facilitated if some common symbols were used in referring to specific portions of the vectorcardiogram. Since Einthoven’s time, E has been used to indicate an instantaneous force. The letter A has been used to indicate an integrated value (area) of the force to include its duration as well as magnitude. These letters have been embellished in a variety of ways by different authors but always to indicate, in reality, a value of all or a part of the electromotive force of the heart as reflected in a presumed axis (x, y, z) or plane (xy, xz, zy), or in three-dimensional space (xyz).

A uniform, easily typed symbolic nomenclature with as close a relation to past custom as possible is visualized as involving the use, without spacing, of a decimal and digits or the capital letter A when indicated, but not E (which is rendered redundant by the digits); of the usual capital letters for specific excitatory or recovery events (P, Q, R, S, T, U, G for QRST, J for S-T junction, S-T for S-T segment); and of lower case letters as indicated for the axes and planes as defined above. For example, .03Px means the instantaneous voltage 0.03 sec after the beginning of atrial excitation manifest in the transverse axial lead; AQRSz signifies the time-voltage area of QRS in the sagittal axial lead.

With oscillographic visualization or recording of the vectorcardiogram in planes or in space, only the P, QRS, and T loops and the point J are easily identified. The components of the QRS loop corresponding to the scalar deflections Q, R, and S are so variable in the different axes and planes that use of the individual letters for referring to portions of the vector configuration is not sufficiently specific. Greater accuracy is achieved by designating vectors temporally, zero time being at the beginning of the P, QRS, or T loop. In the present nomenclature this may be indicated by a decimal followed by digits placed before the designated instantaneous planar or spatial P, QRS, or T vector. For example,.05QRSxy is the vector occurring 0.05 sec after the beginning of the QRS loop in the frontal plane. In the system vector symbols are omitted.

**Glossary**

In order to present meaningful specifications in brief form, the language of the engineer has been employed in much of this report. There are characteristics of engineering language besides a
distinctive vocabulary. The uninitiated physician or life scientist will notice a tendency to employ nouns singly or in groups as adjectives; verbs such as "read" or "record" are converted into modifiers for designating apparatus which does those jobs. The meaning of such wording, though sometimes ambiguous, is usually clear; communicative difficulty between the various groups whose interests converge in electrocardiographic instrumentation lies largely in new words or old words used in new ways. Because the subject matter is of interest to physicians and other nonengineers, a short glossary of terms is herewith attached to facilitate their study of these recommendations.

Accuracy: A degree of conformity to some recognized standard value, or more specifically, the deviation of a result obtained by a particular method from the true value. It is usually expressed as a percentage of full scale. Thus, if the input signal varies between zero and a maximum of 10 millivolts, then the value assigned to the output should be not further from the actual by more than 0.1 millivolt for the accuracy to be within ±1%.

Bit: Contraction for "binary digit"; a unit of information equal to the result of a choice between two alternatives. In terms of the binary system an eight-bit word is capable of holding 2<sup>8</sup> possibilities or values varying from zero to 255 in whole numbers.

Carrier wave: A continuous electromagnetic or radio wave, typically sinusoidal in form and of relatively high frequency, which is altered either in amplitude (AM) or frequency (FM) by a modulating signal of much lower frequency. Thus, it "carries" the information contained in the signals superimposed upon it. When transmitted or recorded, the modulating signal is added to the carrier, and when received or reproduced the carrier is removed leaving the desired signal.

Common mode rejection: The ability of a differential amplifier to reject common signals. The common mode rejection ratio is defined as:

\[
CM_{\text{rej}} = \frac{\text{gain of amplifier to difference signal}}{\text{gain of amplifier to common signal}}
\]

Differential amplifier: A type of amplifier ordinarily employed in electrocardiography designed to amplify the difference between two voltages measured with respect to a common point, usually the right leg. Ideally, no signal which is common to the two active input terminals should appear in the output. In a practical amplifier, however, such a common signal will produce an output (see "Common mode rejection" above).

Distortion: A change in shape of an electrocardiographic waveform introduced by the recording instrument. It is useful to distinguish linear distortion from nonlinear distortion. Linear distortion results when the gain of the instrument for a sinusoidal input is not constant, but depends on the frequency of the sinusoidal signal. The frequency response of an instrument is a record of its gain versus frequency of sinusoidal input. Nonlinear distortion is characterized by an output which departs from a sinusoidal wave shape when the input is sinusoidal.

Frequency modulation: The modification of the frequency of a carrier wave of relatively high frequency in accordance with a signal. For example, if the carrier wave is a sine wave of 4,000 Hz and the signal is an electrocardiographic waveform, the carrier frequency will be progressively raised above 4,000 Hz proportionate to the height of the R wave and dropped proportionally below 4,000 Hz during the S wave.

Gain: The ratio of the amplitude of the output to the input, usually expressed in millimeter/millivolt for a direct-writer, and volts/volt for an amplifier or preamplifier.

Impedance: The total opposition to flow of an alternating current in a circuit. Analogous to the actual electrical resistance to a direct current, the impedance is the ratio of the effective voltage to the effective current. In addition to actual resistance, impedance includes reactance which results from capacitative or inductive properties of the circuit.

Input: (1) The energy (signal) put into an electronic device. (2) The terminal or terminals for the input signal of such a device. (3) The part of the electronic circuit immediately adjacent to the input terminals.

Linearity: Linearity provides a measure of the nonlinear distortion in an instrument (see "Distortion"). Since nonlinear distortions may enter in a number of ways and result in peculiar effects, the linearity specification may be written in several ways. Commonly it deals with the departure from a sinusoidal wave shape for a sinusoidal input. The characteristics of the writing device pose a particular problem in establishing specifications for direct-writers. Linearity as used in this report refers to zero-based linearity. That is, a graphic plot of output voltage (or deflection in the case of direct-writers) versus input voltage will yield a series of points. If a straight line is drawn which passes through the origin, the deviation of any of the actual points from this straight line is a measure of the nonlinearity of the system.
Modulation: The modification of a basic, continuous carrier signal by another information-containing signal. Most commonly the term refers to alterations in amplitude (AM) or frequency (FM) of a sinusoidal carrier wave by the modulating signal. However, the carrier may be a train of pulses which may be modified in width or in frequency by the added informational signal.

Noise: Noise refers to unwanted "signal" introduced from other sources, including the electrocardiograph itself. An example is 60 cycle alternating current "interference."

Output: (1) The power, energy, signal, or information delivered from an electronic device after conversion of the input into another form or modification (such as amplification). (2) The terminals or terminal of an amplifier for delivery of the output. (3) That part of the electronic circuit immediately adjacent to the output terminals.

Parity bit channel: In digital recording systems (paper or magnetic tape), an added bit which acts as an internal checking mechanism for detecting errors in recording.

Precision: The degree of agreement between repeated measurements of a quantity and thus the repeatability of the performance of an instrument. It is desirable for an instrument to be more precise than it is accurate so that the deviation between successive measurements will never exceed the deviation from the value being measured.

Record electronics: In a magnetic tape system, the amplifiers and magnetic heads which convert the input signal into magnetic patterns on the tape.

Reproduce electronics: In a magnetic tape system, a pick-up head and attached amplifiers which convert the varying magnetic pattern from moving tape back into an electrical waveform.

Signal: Signal in this discussion refers to the electrocardiographic waveform attributable to the electrical activity of myocardium.

Signal-to-noise ratio: The ratio of an appropriate parameter characterizing the amplitude of the wanted signal to a similar parameter of the unwanted noise.

Skew: (1) For direct-writers, the departure of the writing stylus from an absolutely vertical swing up or down, that is, from a path perpendicular to the direction of movement of the paper. (2) For magnetic tape, the departure of the moving tape from an absolutely straight course past the magnetic heads. The term is comparable in some degree to "parallax" as used in photographic recording of the electrocardiogram.

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Recommendations for Standardization of Leads and of Specifications for Instruments in Electrocardiography and Vectorcardiography

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