AHA COMMITTEE REPORT

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

Report of the Committee on Electrocardiography, American Heart Association

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Introduction

The last report of the Committee on Electrocardiography of the American Heart Association was published in 1967. Its main departure from previous reports was an increased emphasis on electrocardiographic and vectorcardiographic instrumentation. The general trend toward higher performance standards for biomedical instruments had led in 1964 to the formation of a Subcommittee on Electrocardiographic Instrumentation whose painstaking efforts resulted in the compilation of detailed recommendations on performance standards for electrocardiographs, vectorcardiographs, magnetic tape recorders, and analog-to-digital converters. The latter type of equipment had just appeared on the biomedical scene and was to be used for electrocardiographic data processing.

In the years following the 1967 report, manufacturers of electrocardiographs have made an admirable effort to follow the American Heart Association's recommendations. They contributed with many suggestions to the present report, and their collaboration with the Committee in joint efforts toward achievement of greater excellence in electrocardiographic instrumentation is gratefully acknowledged. This cooperation was furthered by regularly scheduled meetings between electrocardiograph manufacturers and the Committee.

Increasing emphasis on safety and electrical shock hazards led to an amendment of the 1967 report which extended and amplified previously made recommendations on electrical safety.

In the years following the 1967 report, there have been substantial advances in electronic technology and in automated information processing. Those parts of the present report which deal with electrocardiographic and vectorcardiographic instrumentation had to undergo a very thorough revision to reflect these changes.

Thermionic components have almost disappeared and have been replaced by relatively inexpensive, highly reliable, long-life compact high performance solid state integrated circuit modules in a wide variety of functional forms. Automated assembly and testing, printed circuit technology, and modular design now make it possible to achieve much greater reliability, higher performance, and ease of servicing within moderate bounds of cost.

In 1967, the self-standing, direct-writing electrocardiograph was the dominant electrocardiographic instrument in hospitals by a large margin. Today it is still the most widely used instrument but is being supplemented, complemented, and replaced by a wide range of analog, digital, and hybrid systems that now serve to transduce and interface the heart's electrical signature with monitoring, data processing, storage, and display equipment of a wide variety. We must expect this trend to continue, requiring the development of a variety of additional and different standards. Within standard direct-writing electrocardiography, there are new priorities of concern including new attention to systems requirements and

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requirements for environmental electromagnetic compatibility. Electrocardiographs must not only be almost completely free from electric shock hazard to the patient and to the operator even in failure modes, but they must be compatible with other instrumentation likely to be used with them or in the vicinity unless such incompatibilities are clearly understood.

Systems optimization is a guiding theme of the present recommendations on instrumentation. It is essential that instruments be designed and specified to permit quick and easy evaluation of the best compromise that can be achieved between reliable, accurate, and long-life service, safety and ease of usage, and reasonable cost. To assist in achieving this kind of optimality, an outline of the rationale leading to the various recommendations has been included with each section dealing with instrumentation.

Revisions and additions to the parts of the recommendations which deal with electrocardiographic and vectorcardiographic techniques and nomenclature are somewhat different in nature and scope. For the standard 12-lead, which is most widely used, electrode placement is described again in detail for two reasons. First, recommendations on lead placement were published last more than twenty years ago and no longer lend themselves as a convenient reference source. Second, with the increasing emphasis on quantitative electrocardiographic analysis, electrode misplacement has been recognized as a major source of recording error.

The nomenclature for electrocardiographic waveforms and time intervals has been critically reviewed and revised where necessary. The need for better definitions of some of the terms was felt strongly by those who have made attempts to translate existing terminology into the more demanding computer programs languages for automated analysis.

Recording techniques of intracardiac potentials for analysis of the various components of the P-R interval, such as His bundle potentials, represent an addition to the recommendations. Furthermore, a brief outline of recommended techniques for recording isopotential maps from the total body surface was added.

Recommendations for vectorcardiographic recording techniques, data display, and nomenclature are given in greater detail than before in order to facilitate comparison of data from different sources. Regarding vectorcardiographic lead systems, a preference was expressed in the report of 1967 for so-called "corrected" lead systems as compared to the older "uncorrected" ones. No specific lead system was recommended, however, and it was felt that "a more or less natural selection" would take place in the future. The present Committee is in basic agreement with these statements and considers recommendation of a particular lead system for vectorcardiography still unadvisable. As anticipated in 1967, a natural selection process seems to have taken place, and at present the great majority of vectorcardiographers appears to favor the Frank-lead system.

Whichever of the available vectorcardiographic lead systems is selected for use, it is recommended that the directions of the systems designers pertaining to electrode location be strictly adhered to. Arbitrary modifications of lead placement rules have made comparison of data from different sources difficult or impossible.

The electrocardiogram is at present routinely used in intensive care units (ICU) for monitoring the acutely ill patient. Since cardiac rhythm represents the major concern here, requirements in recording fidelity may be relaxed to a certain degree in this application. Unavoidable recording artifacts due to movements of the patients and other causes can be substantially reduced by limiting the frequency range of the recorder both at the upper and lower ends of the frequency band. Similar considerations apply to portable electrocardiographic monitoring devices of cardiac rhythm such as portable tape recorders which increasingly are used in patients with coronary artery disease. Recommendations for electrocardiographic monitor instrumentation are under active consideration by the Committee but are not yet available in final form for publication at this time. They will appear as an appendix to the present recommendations at a later date.

Instruments

A. Direct-Writing Electrocardiographs

1. System performance, linearity, and distortion

The instrument shall reproduce faithfully a contour of any appropriately band-limited (see par. A8), electrocardiographic signal within the limitations of a ±5% amplitude and a 5-millisecond time error, separately applied. For this purpose, the instrument must be capable of reproducing rates of deflection up to 400 microvolts per millisecond which may occur during QRS and of responding to small input signals. Furthermore, small deflections near the base line; e.g., P and Q waves, are often of diagnostic importance and must be recorded with great fidelity.

The deviation of the recorded output from an exact linear representation of the input signal shall not ex-

*At the First International Congress on Electrocardiology in 1974 in Wiesbaden, Germany, 86% of the 52 papers dealing with vectorcardiography were based on the Frank-lead system as compared to 66%, three years earlier, at the XII International Colloquium Vectorcardiographicum in Brussels, Belgium.

*The rationale leading to the recommendations on instruments precedes each paragraph and is printed in italics.
ceed 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. A sinusoidal signal of an amplitude, which ideally would cause a peak-to-peak output of 0.4 mm amplitude, shall not be recorded with an amplitude less than 0.2 mm.

The instrument shall respond with a visible trace within 5% accuracy to a test pulse of either polarity of an amplitude appropriate to produce a peak deflection of 4 cm. This test pulse will rise and fall exponentially, where the turn-on and turn-off times are separated by 100 ± 5 milliseconds and the time constant is 10 ± 0.5 milliseconds.

2. Input range

Peak deflections approaching 10 millivolts, while rare, are encountered clinically.

The instrument shall meet specifications with input amplitudes up to 10 millivolts peak to peak or up to a peak value of ± 7 millivolts with respect to base line 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 within 5 mm of the edges of the record.

3. Input impedance, input current, and electrodes

While the electrical impedance inside the body is usually negligible with respect to that of the input to any recording electrocardiograph, the skin-to-electrode interface is the source of large impedances and substantial potential offsets in surprisingly many patient electrode arrays. The magnitude of errors assignable to this cause is widely underestimated because the distribution of impedances for a group of subjects with practically any electrode system that does not require abrasion or penetration of the skin is approximately logarithmic gaussian rather than ordinary gaussian. Consequently, we must expect to see many electrode preparations with 100,000-ohm impedance in the electrocardiographic frequency range and an occasional one in excess of 1/2 megohm. One can guarantee skin-electrode impedance below 50,000 ohms by mild abrasion, for example, with very fine sandpaper, but it is not safe to assume that such preparations will be faithfully carried out in regular clinical practice. In addition, large polarization offset potential differences occur at the skin-electrode interfaces especially if dissimilar electrodes are used, even if microampere currents flow or if electrodes of easily polarizable types are used.

Buffer amplifier electrodes can greatly simplify the problem of meeting high input impedance requirements, but they may introduce new requirements. So called "capacitive coupled" or "insulated" electrodes can provide very high isolation but will in general require considerations of a new time constant comprised of the electrode-to-skin capacitance and some leakage or designed discharge circuit. Distressing drifts or low frequency response deterioration may be produced. In addition, high potential gradients may be developed with isolated patient systems.

In any position of the lead selector switch, the input impedance measured between any two electrodes shall exceed 5 megohms for frequencies up to at least 60 Hz.

The instrument shall not have DC input currents in excess of 1 microampere in any input line across the permitted range of offset potentials and desirably shall limit these currents to 100 nanoamperes.

The instrument shall operate in the linear range (see par. A1) with up to 200 millivolts of input offset potential difference between input lines in any combination.

Any paste or jelly and electrode combination to be acceptable must result in a skin-to-electrode impedance of 50,000 ohms or less, measured at 10 Hz with currents not exceeding 10 microamperes for at least 75% of a statistically significant number of trials.

4. Central terminal

By convention, a number of leads involve the Wilson central terminal whose potential, ideally, is the mean of the potentials appearing at the right arm, left arm, and left leg. The central terminal potential provided by the instrument should not introduce substantial inaccuracies.

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

5. Sensitivity

To accommodate electrocardiographic signals which may range in peak amplitude from less than 1 millivolt to 10 millivolts and to permit better resolution of low amplitude P and T waves, sensitivities greater and less than the conventional 10 mm per millivolt are required.

Sensitivity is to be adjustable from the instrument panel for at least three fixed levels: 10 mm per millivolt, 5 mm per millivolt, and 20 mm per millivolt. If automatic sensitivity control is provided, provision shall be made for overriding the automatic sensitivity feature from the front panel. An indication of actual sensitivity must be provided when automatic sensitivity control is used. A sensitivity trim capability, if necessary, shall be provided only as an internal adjustment.
6. Stability of gain and base line

Electrocardiographs are often disconnected and moved from patient to patient, while at other times they are required to operate continuously for protracted periods. They should perform satisfactorily under either circumstance.

The instrument shall meet all specifications following a warm-up period of 5 minutes. With the sensitivity set to 20 mm per millivolt and with all patient lead wires connected together with 25,000-ohm resistors inserted in series with any or all of the lines, the base-line drift shall not exceed 1 mm during the next 50 minutes for all positions of the lead selector switch. Within the same period of time, variations in gain shall not exceed 2%.

7. Overload

No damage to the instrument shall result from input currents produced by disconnecting or handling the input leads or electrodes while the instrument is operating. Defibrillator currents are likely to be applied to critically ill patients with an electrocardiograph also connected. The electrocardiograph should be capable of withstanding such currents without sustaining permanent damage.

No permanent disability of the instrument requiring repair shall occur following removal of the electrodes from the patient and the connection of each one in turn through a series 100-picofarad capacitor to the high side of the AC power mains for 5 seconds. During this test, the other input lines are to be within 1 volt of ground.

8. Frequency response

Faithful reproduction of the electrocardiographic waveform, including small notches and slurs, would require an instrument with a frequency response well beyond 100 Hz and with a high chart speed. Conventional electrocardiography, however, has not made use of these more subtle aspects of the waveform, and at this time requiring a direct-writing instrument to have such a wide band response appears unwarranted. A bandwidth from 0.05 Hz to 100 Hz (3 dB down) is necessary in order to insure accuracy for clinically used measurements, such as wave amplitudes and durations. On the other hand, the instrument is not required to exhibit full scale deflection at these high frequencies since high frequency components in the waveform are relatively small in amplitude.

The frequency response shall fall within the limits shown in fig. 1.

a. With an amplitude response of 20 mm peak to peak at 25 Hz, the response to constant amplitude sinusoidal input signals in the range from 0.14 Hz to 25 Hz shall be flat to within ±6% (+0.5 dB). The response to 0.05 Hz shall not be reduced by more than 30% (-3 dB) from the response at 0.14 Hz.

b. With an amplitude response of 10 mm peak to peak at 25 Hz, the response to constant amplitude sinusoidal input signals up to 50 Hz shall be flat to within ±6% (+0.5 dB).

c. With an amplitude response of 5 mm peak to peak at 25 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.

d. At no frequency within the band shall the response exceed the upper limits specified for the range of 0.14 Hz to 50 Hz.

e. Provisions to degrade the performance of the instrument for special-purpose recording shall not be incorporated unless a distinct marking on the record is made whenever this alternative is employed. Any such control shall require continuous action on the part of the operator and shall automatically return to the standard (non-degraded) mode of operation.

9. Common-mode rejection and cross talk

The concept of input signal common-mode rejection was clearly definable and useful when patient amplifier systems almost invariably shared a common reference ground, which was more often than not a direct earth ground. Concerns with system isolation and shock hazard reduction have so greatly changed input circuit practice that a new and somewhat more elaborate specification must be developed that still applied to the older circuits but is appropriate for isolated systems. The human subject, if placed on ordinary dry bedding material, may drift elec-
trosstatically to potentials of at least several hundred volts. In a room not specifically designed to reduce AC fields, the subject may also vary in potential at line frequency with an amplitude which can often be as much as 10 volts with respect to ground.

With an infinite input impedance differential amplifier capable of maintaining very high AC and DC offsets; i.e., common-mode input potentials, the electrocardiographic potential could presumably be measured from such a patient without interference or malfunction. As an alternative, the patient can be held somewhere near a ground of chassis frame potential by a very slight “leak” impedance of no-shock hazard value. In practice, a patient in a relatively bad AC environment will, if grounded, feed a displacement current of a fraction of a microampere to this ground. This is the current the amplifier must cope with or else avoid by isolation.

Ideally, the electrocardiograph should be designed to produce minimal deflections for currents up to 1 microampere. In practice, satisfying such a requirement, while at the same time complying with the recommendations on patient safety described below in par. A12, is very difficult. In our judgment, the safety requirement is paramount. Accordingly, the common-mode recommendation has been relaxed.

For each position of the lead selector switch, with the recorder gain set at 10 mm per millivolt and with all input electrode lines connected together, a 60-Hz 120-volt root mean square (rms) source with one terminal grounded and the other terminal applied to the junction of the leads through a series capacitance of 22 picofarads shall cause no more than 20 mm peak-to-peak deflection. This specification must still be met when a resistance of 100,000 ohms is placed in series with one or more input lines in any combination.

With all input electrode lines connected together, a 10-millivolt 60-Hz signal introduced in turn in series with each electrode shall cause a peak-to-peak deflection not exceeding 1 mm for all positions of the lead selector switch for which the output is ideally zero.

10. Noise level

The noise level of the instrument in general is dependent upon the source resistance which, as noted in par. A3, may be large and variable. Upon simulating a subject by means of completely shielded resistors of 25,000 ohms placed between each patient lead wire and the reference lead wire (or other common point), the output noise with the recorder calibrated to 10 mm per millivolt shall not exceed the equivalent of 0.1 mm rms in any position of the lead switch (10 microvolts rms referred to the input). If any of the resistors are increased to 300,000 ohms, the noise level shall not exceed 0.15 mm rms.

11. AC interference

It should be noted that an AC field at 60 Hz produces 3.8 microvolts per gauss rms per square centimeter of loop area so that a poorly dressed lead near a recorder with a 10-gauss external field could produce a millivolt of interference from its own field in a pair of wires separated by 3 cm for just 10 cm. Fields of 10 gauss or more are not uncommon in hospital locations near instruments or lights, so working areas should be routinely checked with a simple AC magnetometer. The instrument should not be sensitive to moderate electric or magnetic fields in which it must operate. Neither should it generate excessive fields which might interfere with the operation of other equipment or with its own operation.

The instrument shall not be deteriorated in performance by AC electric ambient potentials up to 250 volts rms referred to ground or field strengths up to 100 volts per centimeter in the subkilohertz frequency range or by 0.1 volt per centimeter fields in the broadcast band. The instrument shall not deteriorate in performance when immersed in uniform fields of 10-gauss rms intensity or in gradients of up to 1 gauss per centimeter in any direction or configuration at AC line frequency and its first five harmonics and three subharmonics. Sensitivity within this limit should be specified. The level of immunity of the instrument to radio frequency (RF) should be specified and should cover the range from power frequency to 30 gigahertz; i.e., 1-cm waves.

The instrument (including power cables) shall not produce external AC electric fields with potentials in excess of 5 volts with respect to a proper ground or in excess of 1 gauss rms unless the field is specified and its decrease with distance and its orientation are specified.

12. Safety and electrical shock hazards

Considerations of patient safety have led to a recommendation for an upper limit for line frequency current leakage and to a recommendation for isolation from ground of metallic portions of the apparatus accessible to either the technician or the patient. An upper value for alternating current leakage of 10 microamperes was adopted because it is half the lowest value reported to have produced fibrillation with line frequency current. Even with such small current values, current density at the electro-myocardial interface, the physiologically significant determinant of ventricular fibrillation, may be very high. Significantly, alternating current leakage values smaller than 10 microamperes have been achieved in contemporary AC powered electrocardiographs by a variety of techniques. The recommendation regarding isolation of any lead or accessible portion of the ap-
paratus is necessary to prevent shock hazards when an electrocardiograph is connected to a patient already in contact with devices having higher alternating current leakage. Admittedly, both leakage and grounding recommendations have been drawn with a worst-case situation in mind; e.g., connection to a conductor connected directly to the heart. However, this latter procedure is so common in hospitals as to abundantly justify these specific recommendations.

All electrocardiographic and/or vectorcardiographic apparatus shall be designed so that no more than 10 microamperes rms, DC to the tenth harmonic of power-line frequency, shall be measurable between any two of the following: 1) electrodes; 2) case; 3) other accessible part normally or potentially in contact with the patient; and 4) power-line ground at the receptacle from which the electrocardiographic/ vectorcardiographic apparatus is energized.

A 500-ohm resistance shall be placed between the two parts under study, and the current shall be determined by measuring the rms voltage across the resistor with a high impedance meter. An oscilloscope should be employed in parallel with the meter in order to determine the waveform of the currents present. The rms voltage measured between any of the items above shall be less than 5 millivolts (current through 500 ohms less than 10 microamperes), regardless of an interchange of power-line neutral and hot connections and despite disconnections of power-line ground. These measurements are to be repeated for all pairs of parts referred to above. For details of the circuit configurations, refer to paragraphs 266-272 in Standards for Safety, Medical and Dental Equipment, Underwriter's Laboratories, UL 544, May 30, 1972.

The upper limit of current (10 microamperes) must not be exceeded if: 1) a single insulation failure occurs in a line-operated component such as power cord, transformer, or chart motor; 2) a single failure occurs in an electronic circuit critical to patient isolation, such as, but not exclusively, a first-stage preamplifier or electrode buffer amplifier; 3) an incorrectly wired, three-wire receptacle is used to energize the electrocardiograph; and 4) the power-line ground is disconnected. In addition, no path shall exist between an electrode and power-line ground where 60-Hz impedance is less than 20 megohms with up to 120 volts between the electrode and ground.

If equipped with a three-wire power cord, the power plug shall be a moisture-resistant "hospital grade" variety constructed so as not to shatter or disassemble after a glancing blow, with strain relief loops in the ground and neutral connections only. Barriers of insulating material shall mechanically separate the three screw terminals, but the barrier around the "hot" terminal shall be significantly higher than the others. The plug shall not be of the twist-lock or other variety restrainable in the receptacle.

13. Calibration ("standardisation")

The calibration pulse has traditionally served four distinct purposes. 1) It provided a means for calibrating the sensitivity of the instrument. 2) It indicated the position of the sensitivity selector switch. 3) If inserted in series with the patient lead, it provided an indication of continuity in the patient connection. 4) Its shape provided a crude indication of the frequency response of the instrument.

While excellent stability is now available from proper design of some circuits, the necessity for a calibration signal to achieve the first purpose has not yet been obviated. The calibration signal should be inserted as close to the patient connection as possible in order that it passes through all stages of amplification and signal processing. Particular input circuits designed for patient safety may pose special problems for the insertion of a calibration signal, yet their added complexity would seem to dictate the desirability of including them in the calibration path. Buffer amplifiers may require an alternative means of testing lead continuity.

The standardizing voltage shall be a signal of 1.0 millivolt ±2% with a rise time of less than 1 millisecond and a decay time of not less than 100 seconds. This voltage shall be applied to the circuit by a switch on the panel of the instrument and shall be capable of being applied while the electrocardiogram is being recorded. 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 standardization voltage whether or not the patient is connected to the instrument. If a battery is used for obtaining the standardizing voltage, the instrument shall be provided with an indicator to alert the user when the battery is no longer capable of supplying voltage to the required accuracy. When applying the calibration voltage at the patient electrodes is not practical; e.g., when particular patient isolation circuits or buffer amplifiers are used, provision shall be made nonetheless for verifying the overall sensitivity of the instrument as well as lead continuity and the absence of excessive impedance at the electrodes.

14. Chart speed

The conventional chart speeds of 25 and 50 mm per second appear to be satisfactory for most uses, although 100 mm per second is desirable for certain applications; e.g., measurement of systolic time intervals. Accuracy must be such as to permit reliable
measurement of intervals associated with a single beat over the short term and of average heart rate over the long term.

A minimum of two speeds including 25 mm per second and 50 mm per second shall be available. Speed variations shall not exceed ±5% over time intervals as short as 0.1 second and ±2% over time periods longer than 5 seconds when operating from the specified power source. Time markings at 1-second ±2% intervals 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 chart

Accuracy of chart markings must be consistent with overall accuracy requirements of the instrument.

The recording chart shall be ruled with 1.0-mm divisions along both time and voltage axes. Every fifth division shall be accentuated. The rulings shall be controlled to within a 2% overall standard which shall be met throughout a temperature range from 10° C to 50° C and for relative humidities from 10–95%. The ruled divisions shall preferably cover a total of 5 cm in width, and the recording shall be rectilinear.

16. Skew and temporal alignment

To assure time coherency in multichannel instruments and rectilinearity in each channel, maintaining positional coherency on the time axis for recorded events of any amplitude is important.

a. With the paper drive off, a calibration signal of 10-mm vertical deflection shall be inscribed with no more than 0.1 mm of horizontal displacement.

b. With the amplifiers for each channel of a multichannel instrument 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. Trace width

Excessive trace width may cause loss in precision in measurement of amplitudes and durations, but some clinicians prefer a moderately wide trace width for emphasizing particular features of the waveform.

The vertical width of the undeflected trace shall appear uniform and shall not exceed 1.0 mm at any operating chart transport speed. The instrument shall respond with a clearly visible trace to any input signal meeting the requirements specified in pars. A1 and A2.

18. Auxiliary output (optional)

An auxiliary jack for a direct-writing instrument is not required. It will be useful when the instrument is to be used as an electrocardiographic amplifier whose output will drive a tape recorder, oscilloscope, computer, etc. Under these circumstances, the frequency response of the signal available should have a broader band than that required for the direct-writer output on paper.

If a jack is available for gaining access to the output, the signal at this jack shall have a driving capability of at least ±1 volt full scale for loads exceeding 10,000 ohms. Output impedance shall be less than 100 ohms. The output characteristics shall be the same as specified in pars. A1 and A3 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 0 volts.

No damage shall occur to the instrument when the output is short-circuited. Upon removal of the short-circuit, the instrument shall be capable of meeting specifications. Connection of this output to another instrument which is improperly grounded shall not cause the electrocardiograph to fail to meet safety and electrical shock hazards as specified in par. A12.

19. Trace reset

Following off-scale deflection due to lead handling, patient movement, or other transient artifacts, the instrument must quickly return to an on-scale position.

If an automatic, self-balancing feature ("base-line clamping," "self-centering") is not provided, a capability for manual trace reset must be provided by a switch or button on the instrument. After a 10-millivolt pulse has been applied to the input for 10 seconds at a sensitivity of 20 mm per millivolt, actuating this button or switch shall cause the trace to return to within 1 mm of its initial position within 0.5 second. Releasing the button or switch after it has been actuated for more than 0.5 second shall result in no more than 1 mm of additional displacement. The trace shall return to within 1 mm of its initial position within 0.5 second following any change in position of the lead selector switch when all patient lead wires are connected together.

20. Power-line variations

For instruments adjusted for operation 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 of up to 3,000 meters above sea level and at relative humidities from 5% to 95%.

22. Standardization of controls

Electrocardiographs shall be equipped with the following controls labelled as shown in quotation marks:

- "Paper Speed" Multiple-position switch
- "Off-On-Run" Three-position switch
- "l mV" Momentary contact switch
- "Lead" Multiple-position switch
- "Center" Knob
- "Reset" Push button or switch
- "Sensitivity" Three-position switch

* mV and/or reset switches may be automatically controlled. If any of the foregoing controls or knobs contain accessible metallic elements, they must meet the specifications on alternating current leakage (par. A12).

23. An electrocardiographic waveform generator for testing, standardization, and comparison of electrocardiographic recording and reorienting systems

The availability of a family of testing devices that will permit simple and reliable testing and maintenance of electrocardiographic devices is desirable. In order to be properly applicable to a wide range of instruments of diverse design and manufacture, these devices should be as little specialised as possible within reasonable cost ranges.

A device of this type should meet two related but different needs. 1) It should provide a set of different and reliable coherent body surface potentials that closely simulate real normal and typically abnormal electrocardiographic/vectorcardiographic signatures. 2) It should provide a set of technical testing signatures designed to permit easy quantitative assessment of performance in the many aspects dealt with in the body of this report.

A device of this type might, for example, provide an output terminal to correspond to each of the commonly recorded anatomical positions; e.g., LA, RA, LL, RL, V1, a, or others. These would permit scalar, vector, and even innovative new systems to be tested and compared. In its alternate mode, accurate step and ramp signals for frequency, amplitude, and channel identification testing would be provided.

24. Color coding and lead identification

Color coding for patient leads ideally should result in uniform colors for electrocardiographs used in the USA and, preferably, world-wide. For single-channel conventional-lead electrocardiographs, commonly used colors for USA machines differ from those used in much of Europe. The International Electrotechnical Commission (IEC) has proposed a standard compatible with the European custom. The USA color coding has been in use for so long that the confusion that could result from trying to become compatible with the IEC proposal is a clear disadvantage. Therefore, this Committee continues to recommend the same color coding as specified in previous reports.

For three-channel conventional-lead electrocardiographs, no present USA standard exists, and in the interest of compatibility, color coding for precordial leads has been made almost compatible with that proposed by IEC. The major difference between the two is that brown is the common color for V1 through V6, rather than white, as proposed by IEC. In addition, brown/white and brown/black combinations have been avoided to permit easier identification. A color code has also been suggested for a Frank-lead cable only because of the widespread use of this lead system.

Three-channel electrocardiographs with combined patient cables for recording both conventional and Frank leads have become commercially available. Color coding in this case should be compatible with the colors recommended below for the separate Frank leads and conventional leads.

Colors may be associated with either individually colored lead wires or with plug bodies if used at the lead ends. Cable legends of a permanent type, such as engraving, shall also be used for individual lead identification. For those leads requiring two colors, the minor color may be that used for the cable letter identification, provided that the identification appears in at least two places.

**Conventional Leads, Single Channel**

| Lead | Color   |
|------|---------|
| RL   | Green   |
| LL   | Red     |
| RA   | White   |
| LA   | Black   |
| V1–V6| Brown   |

**Conventional Leads, Three Channel**

| Lead | Color       |
|------|-------------|
| RL   | Green       |
| LL   | Red         |
| RA   | White       |
| LA   | Black       |
| V1   | Brown/Red   |
| V2   | Brown/Yellow|
| V3   | Brown/Green |
| V4   | Brown/Blue  |
| V5   | Brown/Orange|
| V6   | Brown/Violet|
B. Stand-Alone Amplifiers

Since the last report, the scope of cardiac electrophysiological signals of clinical interest has increased considerably. Consideration must be given to the standard electrocardiogram and vectorcardiogram, to the esophageal lead, to the foetal electrocardiogram, to body surface mapping, and to patient monitoring in the operating room, the recovery room, and the intensive care unit. Signals may be recorded from skin electrodes, catheter electrodes, or epicardial electrodes. Each application places different demands on the recording system. In several cases, the requirements on the fidelity of the signal from a clinical standpoint are not yet well established. Furthermore, modular units may be put together to make systems which are appropriate for particular needs.

The important consideration of the overall system behavior should be emphasized. Detailed recommendations for items such as gain and frequency response would appear inappropriate for stand-alone general purpose amplifiers because of their diverse applications. By contrast, the direct-writing electrocardiograph is a complete system designed for a rather limited application for which spelling out recommended standards of performance in considerable detail is possible (and desirable).

Recommended performance requirements

All amplifiers must satisfy the safety and shock hazard requirements of par. A12.

The deviation of the output signal from an exact linear representation of any input signal in the pass band of the amplifier shall not exceed 2% of the peak-to-peak output for input amplitudes between 0.5 and 10 millivolts. For peak-to-peak input amplitudes below 0.5 millivolt, this deviation shall not exceed 10 microvolts referred to the input.

An amplifier to be used for standard electrocardiography shall have a frequency response which is flat to within 6% from 0.14 to 1,000 Hz for input signals with peak-to-peak amplitudes up to 10 millivolts. At no frequency within the band of 0.05 to 2,500 Hz shall the response exceed the upper limits specified for the range of 0.14 to 950 Hz. High-pass and low-pass filters with variable cut-off frequencies may be provided for special applications.

Where applicable, the amplifier shall meet the performance standard recommended in pars. A2, A3, A4, A6, A7, A9, A10, A11, A13, A19, A20, and A21.

C. Vectorcardiographs

Vectorcardiography imposes only a few special requirements beyond those of a scalar electrocardiograph. Because of the concern for detailed time relationships among coherent signals and the extended frequency capabilities of cathode-ray display, these systems currently respond into kilohertz regions. Vectorcardiography is a coherency analysis that is intrinsically sensitive to timing-error differences between amplified signals. Because displaying selected sections of the vectorcardiogram in extended form is common practice, either the displayed beat must be stored or the expected period during which a segment to be displayed will occur must be approximately predicted from a preceding beat. The considerable variations in actual trace speed during the several base lines and other portions of the vectorcardiogram make special demands on the display recording and time marking practices. Brightness modulations or other procedures should generally be used to make all of the trace accessible for measurement.

1. System performance, linearity, and distortion

Allowing for a maximum of 10-microvolt input noise, any deviation of the display from an exact linear representation of the input signal shall not exceed 5% of the ideal output for input amplitudes up to ±10 millivolts when displayed at 75% of the allocated display space. When an input signal is applied simultaneously to both the horizontal and vertical channels, any deviation of one output from the other shall fall within the same limits. When P and T waves are recorded at higher sensitivity, distortion of the QRS complex is permitted provided that the registration of the P and T waves continues to meet this specification.

2. Input impedance, input current, and electrodes

Recommendations for allowable input loading, offset potentials, and electrodes in par. A5 shall apply.

3. Sensitivity

Gain should be adjustable in fixed steps to provide full-scale output for input amplitudes in the range from 1 to 10 millivolts. Gain accuracy must be maintained within ±1% after an initial warm-up period not to exceed 2 minutes. Gain of the horizontal and vertical channels shall agree within ±1%. Provision shall
be made for registration of P and T waves at ten times greater sensitivity.

4. Frequency response

When operating in a mode suitable for display of the QRS complex, the instrument shall have a response to constant amplitude sinusoidal signals which is flat to within ±6% (±0.5 dB) from 0.14 to 1,000 Hz. The response from 0.05 to 2,500 Hz shall not be reduced more than 30% (−3 db), and at no frequency shall the response exceed that specified for the 0.14 to 1,000 Hz range.

For high-gain registration of the P wave or the T wave, the instrument shall have a front-panel provision for lowering the high-frequency response in several discrete steps to a minimum of 100 Hz.

5. Time marking

The instrument shall contain provision for time marking of the vector loops and scalar leads. If the mark is of tear-drop shape, it shall have its blunt edge leading in order to indicate the direction of loop rotation. The basic interval between marks shall be 2.5 milliseconds. For clarity in recording P and T loops, provision shall be made for timing intervals of 5 and 10 milliseconds. The instrument shall have a provision for temporary inactivation of the time marker.

6. Weighting networks

The magnitude of the deflection for all leads derived from weighting networks shall not deviate from their correct values by more than an additional 2% from the allowable deviations specified in par. C1. This specification shall continue to be met in the presence of variable skin-to-electrode impedances up to 100,000 ohms.

7. Selective display

Provision shall be made for selectively displaying in their entirety the P wave, the T wave, and the QRS complex.

8. Safety and electrical shock hazards

Requirements of par. A12 must be met.

9. Calibration

Since calibration can be accomplished in various ways, only one of many possible procedures will be described here to illustrate the principles involved. Simultaneous application of a ramp signal to all inputs, a pair at a time for each projection plane (xy, xz, zy), permits checking of phase coherence. 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.

A 1-millivolt calibration signal shall be provided for simultaneous application to all channels. Plane projections and component leads of each plane should be clearly identified. 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 in fig. 2.

10. Lead continuity

Provision shall be made for checking electrode contact and lead continuity.

11. The vectorcardiograph should meet the performance standards recommended in pars. A6, A7, A9, A10, A11, A19, A20, A21, and A24.

D. Magnetic tape recording of the electrocardiogram

In many circumstances, storing electrocardiograms for later hard copy and analysis is useful. The basic requirement on a tape recording system is that no significant distortion be added to the signal; i.e., the analysis or reproduction of the signal should be essentially the same as if the signal had not been stored on tape. Requirements will depend on the particular application. The availability of the recording for perhaps unknown future use would seem to dictate that the signal be preserved with as great a fidelity as
is consistent with its observed characteristics. Unfortunately, greater demands on the recording system will result in significantly increased costs, and some compromise appears desirable between requirements on signal fidelity and the costs of recording and storing data.

1. Direct-writer application

When an electrocardiogram is tape recorded exclusively for later reproduction on a direct-writing instrument, the reproduced signal shall meet the specifications contained in pars. A1 and A8. Speed variations shall be compatible with par. A14. In addition, noise due to recording and reproducing shall not be greater than 10 microvolts rms, referred to the electrode potentials.

2. Extended applications

Tape-recorded electrocardiograms which are intended to be analyzed by more detailed methods than direct writing shall be governed by more stringent specifications, appropriate to the fidelity of the particular data processing system. In addition to those contained in the above paragraph, the following recommendations apply:

a. Time disparity between any two electrocardiographic signals caused by tape skew or head scatter shall be no more than 1 millisecond.

b. The bandwidth shall extend to at least 500 Hz. When the record is intended solely for reproduction in a system employing a reduced data rate (e.g., a computer program with a sampling rate of 250 per second), this specification may be reduced appropriately.

c. If an electrocardiogram is to be reproduced utilizing a different machine from that on which it was recorded, all the above specifications shall be met. For convenience in interchange of recorded data, the specifications of the Inter-Range Instrument Group (IRIG)* are convenient and standardized.

E. Electrocardiographic data processing

Analysis of electrocardiographic data using automated methods has progressed to the point where a substantial proportion of patient records are processed automatically. In one modality, a computer can be used to generate certain measures of the electrocardiogram such as wave amplitudes, intervals, and instantaneous vectors. Alternatively, the computer can be programmed to classify electrocardiograms according to disease state, with or without the explicit generation of measures. Although standardization of methods for analysis is impractical at this stage of development, a number of general recommendations may be made concerning some aspects of data processing with a goal of establishing guidelines for achieving appropriate fidelity for the several waveform measures. These recommendations are mainly directed towards data processing techniques which have become more widely used; they are not intended to restrict or discourage innovative or unconventional methods for achieving the same results.

1. Sampling

Conventional processing of electrocardiographic voltages for digital computer measurements and analysis requires that the continuous waveforms be converted into digitally sampled data. As a minimum requirement, reconstruction of the original electrocardiographic waveform with a fidelity comparable to that of a direct writer can be accomplished with equal interval sampling of 500 per second, digitized with a precision of 10 microvolts, referred to electrode potentials. When more than one electrocardiographic lead is coherently digitized, a time discrepancy no greater than 1 millisecond between any two leads is acceptable to retain temporal alignment.

Sampling and quantization methods other than the above; i.e., nonuniform sampling rates or lower rates and precision, may be fully acceptable either for reconstruction of the original waveform or for inputs into specific analysis programs, but when such methods are used, the performance of such systems shall be adequately documented.

2. Transmission by telephone and radio

Transmission of electrocardiographic signals via voice data telephone lines is commonly accomplished using various recording methods such as frequency modulation. The performance of analog frequency division multiplexing modems for transmitting several signals simultaneously is limited primarily by such voice-channel characteristics as phase jitter, nonlinear distortion, and limited bandwidth. Signal integrity of the electrocardiographic waveform from transmitting to receiving end should meet the requirements set forth in pars. A1, A8, and A20.

Additional noise introduced by the telephone transmission process shall be no more than 10 microvolts rms, referred to electrode potentials.

Frequency response to 100 Hz can be met using FM transmission of three-frequency multiplexed electrocardiographic signals over voice data lines. Center carrier frequencies of 1,075, 1,935, and 2,365 Hz have

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*IRIG standards govern tape width and thickness, track geometry, head and head-stack configuration, tape speeds and speed tolerances, center carrier frequencies and frequency deviations, and bandwidth. Details may be found in IRIG Document No. 106-73, "Telemetry Standards," Secretariat, Range Commanders Council, White Sands Missile Range, New Mexico, 88002.
been somewhat standardized for voice data lines in the USA. Specialized methods for emphasizing certain frequencies are sometimes used, thus preventing complete compatibility of transmission and receiving equipment. Users should be aware of such problems when transmitters and receivers of different types are used together.

Since telephone equipment is subject to heavy current surges, from lightning for instance, it should be capable of handling such surges so that they are not potentially hazardous to patient or operating personnel. This is especially important if conductive or capacitive coupling to the subject is used. Accessible surfaces and controls of modems, data access arrangements, etc., which interface with telephone lines should be nonconductive.

Telephone transmission using analog encoding is often subject to capricious noise problems which usually become more severe as the distance between transmitting and receiving terminals increases. Since subtle distortions of the received waveform may result, routine application of performance testing procedures to detect incipient problems is recommended.

Digital data transmission of electrocardiograms over telephone lines has not been widely utilized because of bandwidth limitations of voice data lines; however, techniques currently being developed, including non-real-time encoding and data compression, are expected to permit electrocardiographic transmission requirements to be met. Verification methods, such as echo-parity checking, may make digital transmission more reliable than other methods, but performance testing procedures are strongly recommended.

3. Storage and retrieval

Alternative modes of data storage and retrieval, such as magnetic strip, electric strip, or optical recording, shall be expected to provide reconstituted signals of quality at least equivalent to that required of tape recording systems as specified in section D., Magnetic tape recording of the electrocardiogram.

If electrocardiographic storage is in the form of measurements to be used for comparison with measurements of other electrocardiographic signals, these measurements should be retrievable with a precision of at least 10 microvolts referred to electrode potentials for amplitudes and 2 milliseconds for durations or intervals. Accuracy of the measures shall be consistent with the requirements of pars. A1, A16, and C1.

Leads

A. Techniques, Scalar

The techniques described in previous reports1-3 for recording bipolar extremity leads, unipolar extremity leads, and unipolar precordial leads have become widely accepted, and these leads constitute what is often referred to as the standard 12-lead electrocardiogram.4 Since inaccuracy in electrode placement represents one of the major sources of error in electrocardiographic recording, delineating the recommended electrode locations in this report again appears appropriate.

1. Bipolar extremity leads

Bipolar extremity leads record the potential difference between two extremities when each is connected to one of the input terminals of the recording device. The difference in potential between the left arm and the right arm is designated as lead I; between the left leg and the right arm, as lead II; and between the left leg and the left arm, as lead III. The first named extremity of each pair should be connected to the positive terminal of the input device.

The electrodes may be placed on any part of the arms or of the left leg as long as they are below the shoulders in the former and below the inguinal fold anteriorly and the gluteal fold posteriorly in the latter. Any other placement necessary by deformed or missing extremities must be noted on the record.

2. Unipolar extremity leads

Unipolar extremity leads were designed to record potential variations of a single extremity in reference to an "indifferent" electrode, Wilson's "central terminal." The latter was thought to represent the mean potential of the body during the cardiac cycle. It is formed by connecting three extremity leads (left arm, right arm, left leg) through equal resistors to a common terminal which in turn is connected to the negative input terminal of the recording device. The recommendations for input impedance (see Instruments, par. A3) and central terminal accuracy (see Instruments, par. A4) combined with the recommendation on common-mode rejection (see Instruments, par. A9) impose certain stringent requirements on the input circuitry and the values for the central terminal resistors which must be more than 300,000 ohms each if conventional circuitry is used. If resistances less than this are used, voltages of the leads are likely to be distorted. To meet the specification for common-mode rejection, a resistor which has one-

*The Committee considers the use of the terms "unipolar" and "bipolar" leads to be justified for this section on the basis of their widespread use in clinical medicine. Explicitly, there is no such thing as a "unipolar" lead as all potential measurements are in fact potential difference measurements. Therefore, the term "unipolar" preferably should not be used. Bipolar measurement is to be understood as the type of measurement which is made when using a differential amplifier with the input lines at the "bipolar" positions.
third the value of the central terminal resistor may need to be inserted in series with the exploring electrode. Under such circumstances, the differential input impedance of the preamplifier would need to be greater than 20 megohms.

The recommendations on input impedance and common-mode rejection may be met using lower values for central terminal resistors and preamplifiers with lower input impedance by using other than conventional circuitry; e.g., a buffer amplifier for each active electrode.

When recorded in addition to bipolar extremity leads, the information content of unipolar limb leads is completely redundant since two independent potential differences between extremities provide all electrocardiographic information which can possibly be derived from extremities. The usefulness of these leads, therefore, has frequently been questioned. Application in clinical practice has become so ingrained, however, that continued use is to be expected.

Severing the connection between the extremity being studied and the central terminal is common practice in order to augment the amplitude of the recorded deflections. Designations of these augmented unipolar extremity leads are \( aV_H \) (right arm), \( aV_L \) (left arm), and \( aV_F \) (left leg).

3. Unipolar precordial leads

As in unipolar extremity leads, the exploring precordial electrode is connected to the positive terminal of the recording device with the negative terminal connected to the central terminal. Leads obtained in this way are designated by the letter \( V \) (for voltage) followed by a subscript indicating the location of the exploring electrode according to the following plan: Lead \( V_1 \) indicates a lead from the right sternal margin at the fourth intercostal space; Lead \( V_2 \) is taken from the left sternal margin at the fourth intercostal space; Lead \( V_4 \) is taken from the left intercostal space at the fourth intercostal space; Lead \( V_5 \) is taken from the fifth intercostal space where it intersects with the left midclavicular line; \( V_3 \) indicates a point midway between leads \( V_2 \) and \( V_4 \); Lead \( V_6 \) is taken from the junction of the left anterior axillary line with the horizontal level of \( V_4 \); Lead \( V_9 \) indicates a lead where the left midaxillary line crosses the horizontal level of leads \( V_4 \) and \( V_6 \). Occasionally, additional leads, \( V_7 \) and \( V_8 \), are recorded. They are taken from the same horizontal level at the left posterior axillary line and the left midscapular line respectively. When leads are recorded from the right side of the thorax, their locations are to be designated by arabic subscripts, as is done for the left side, and followed by the letter \( R \) (for right) also in subscript. A lead from the fifth intercostal space in the right midclavicular line thus will bear the designation \( V_{4R} \).

If a lead is made from the tip of the ensiform, it shall be designated by a lower case \( e \) as the subscript; e.g., \( V_e \).

4. Esophageal leads

In the case of unipolar recording, the exploring electrode is preferably a small cylinder, approximately 3 mm by 4 mm, made of noncorrosive metal. It is connected by insulated wire of appropriate length to a connector at the end of a small bore tube which leads to the positive input terminal of the recording device. The central terminal, as described above, may be used as an indifferent electrode, leading to the negative input terminal.

For bipolar esophageal leads, two-ring electrodes insulated from each other at a distance of 20 to 50 mm may be arranged in the vicinity of the tip of the tube. By convention, the proximal electrode of the pair should be connected to the positive and the distal electrode to the negative input terminal of the recording device.

The depth of an electrode in the esophagus is measured from the anterior nares or the incisor teeth. For bipolar electrodes, a position midway between positive and negative ring electrodes shall be used for indication of the depth. In adults, lead positions close to 40 cm from the anterior nares are usually in the vicinity of the left atrium; and at 50 cm, close to the left ventricle. These distances are slightly shorter when the incisor teeth are used as reference level.

Bipolar lead recordings should be designated by the upper case \( E \), followed by a numerical subscript indicating the electrode depth in centimeters; e.g., \( E_{35} \), \( E_{42} \). Unipolar esophageal leads are designated by the symbol \( V \) followed by an upper case subscript \( E \) and a number to indicate the distance from the anterior nares; e.g., \( V_{E35} \), \( V_{E42} \).

5. Endocardial leads

Unipolar or bipolar techniques of recording from intracardiac sites may be used. In the case of unipolar recording, the exploring or endocardial electrode may be a small cylinder, approximately 2 mm by 3 mm of a noncorrosive metal, located near the end of a standard solid cardiac catheter. The electrode should be connected by insulated wire within the catheter to the input terminal of the recording device. As for other unipolar leads, the central terminal (see Instruments, par. A4) may be used as the indifferent electrode. Due to the relatively large amplitudes of intracardiac potentials, the amplifier gain of the recorder has to be adjusted accordingly. A calibration signal is to be recorded with each lead.

For bipolar recordings, two or more ring electrodes may be affixed at a distance of approximately 2 mm from the weighted tip of a 110 to 120 cm solid catheter of French sizes 6, 7, or 8. The ring electrodes are
usually 1 mm in width and 2 to 3 mm in circumference. Distances between recording electrode pairs may range from 1 to 10 mm. Leads with close inter-electrode distance facilitate more precise location of the signal source.

Placement of intracardiac electrodes is done most accurately and safely with the aid of an image-intensifier fluoroscope. In patients too ill to be moved, experienced operators may place electrodes by continuous monitoring of intracardiac or intravascular potentials.

Endocardial recordings as other invasive techniques require particular care and great emphasis on the safety requirements outlined under Instruments, par. A12.

When unipolar leads are used, they are designated by the symbol V, followed by an upper case subscript, indicating the area of recording. For example, $V_{IVC}$, $V_{SVC}$, $V_{RA}$, $V_{RV}$, $V_{PA}$, and $V_{HB}$ indicate leads from the inferior vena cava, the superior vena cava, the right atrium, the right ventricle, the pulmonary artery, and the His bundle area. Designations such as RA, RV, PA, or HB, without the prefix $V$, indicate bipolar leads from the same areas. Because electrode location within the atria has become increasingly important in estimating intra-atrial conduction time, the symbols HRA and LRA are used to indicate bipolar recordings from the high or low right atrium, respectively.

When efforts are made to record deflections from the region of the Bundle of His, this can be accomplished from bipolar electrodes at the tip of a catheter, as described above. Such a catheter is introduced into a femoral vein and passed through the right atrium and across the tricuspid valve. From there it is slowly withdrawn until the deflections of interest, representing atrial, His bundle, or ventricular activation, are identified. A number of techniques for verifying the origin of the deflections may be utilized. If a reproducible record with appropriate temporal components in the PR segment is obtained, the source of the deflections can be postulated with a fair degree of accuracy. Fig. 3 demonstrates a set of simultaneous recordings with time measurements of the PR-interval subdivisions in milliseconds. Since locating a discrete and reproducible point of onset of the waves representing atrial, His bundle, or ventricular activation is sometimes difficult, the following recommendations may be of help in achieving an acceptable level of reproducibility and accuracy.

A minimum of three body surface leads, as nearly orthogonal as possible, should be recorded simultaneously with the intracardiac leads. Frequently, although not always, the earliest evidence of atrial activation will manifest itself in one of the surface leads. In order to estimate qualitatively intra-atrial conduction time, measuring the interval from a point in the surface lead in which the earliest onset of atrial activity occurs to a reproducible point on the A wave, recorded near the atrial-nodal junction, is necessary. This interval is designated as the P-A interval and provides an approximation of conduction time between those regions of the atria which are activated earliest and those which represent late activity from lower regions. In some laboratories the earliest baseline departure of the A wave, in some others the peak of A, is used for time-interval measurements. Both techniques appear acceptable, but a clear indication of the method used should be provided. Similar considerations apply to His bundle deflections. While identifying the earliest onset of these deflections may be desirable, this is sometimes difficult because the low frequency components at the departure from the base line are frequently less reproducible than the more distinct-positive or negative peak deflections.

While the interval between the A wave and the His bundle deflection (H) provides an estimate of AV nodal conduction time, the HV interval, between H and the earliest departure from the base line of the ventricular complex in any one of the leads, gives an indication of the transit time from the His bundle to that part of the ventricles which is activated earliest. If an intracardiac lead is selected to indicate the onset of ventricular activation, the HV interval may be longer than that derived from orthogonal body surface leads. This is probably due to the limited recording range of the bipolar intracardiac lead which may not include

![Figure 3](https://example.com/figure3.png)

*Figure 3*  
Body surface lead (top) and bipolar intracardiac lead (bottom) used for timing of lower atrial activity (A), His bundle potential (H), and beginning of ventricular depolarization (V). Time intervals are in milliseconds.
early activated sites of the lower septum. In pre-
excitation syndromes, the converse can be found
where the catheter lead may record ventricular ac-
tivity earlier than the surface leads.

Because of presently prevailing differences in re-
cording techniques and in methods of measurements,
development of binding and detailed specifications for
intracardiac recording of temporal components of the
PR interval (fractionated PR intervals) appears inap-
propriate at this time. In more general terms, the
following recommendations can be made:

a. A minimum of three relatively orthogonal leads
should be recorded together with the intracar-
diac lead.
b. For measurements of time intervals, reproduc-
ible points should be selected in each recording
with clear indication of the method used for
selection.
c. Attempts should be made to determine normal
limits for time intervals based on methods used
in a given laboratory.

6. Isopotential body surface maps

To record isopotential body surface maps, leads
should be obtained both from the front and the back
of the thorax. A clear indication of electrode locations
according to anatomic landmarks on the torso and
inter-electrode spacing should be provided. In order
to allow accurate timing of electrical events in all
leads, three or preferably more tracings should be
recorded simultaneously with one lead serving as a
constant time reference.

When unipolar records are taken, as is commonly
done, the exploring electrodes should be connected to
the positive input terminal of the recorder with the
central terminal connected to the negative terminal.
Calibration should be provided for each map.

B. Techniques, Vector

Recommendations pertaining to instruments for
recording vectorcardiograms have been described
earlier under Instruments, section C., Vector-
cardiographs.

1. Polarity of leads

Previous principles laid down for designation and
polarity of leads still apply.1 The transverse,
longitudinal, and sagittal leads used in vectorcar-
diography shall be named x, y, and z respectively.
They are shown diagrammatically in fig. 4. Custom
and increasing knowledge of the excitatory process
have dictated the choice of polarity since the mean
direction of excitation in the ventricles is directed
downward, to the left and backward. This choice
satisfies also the convention of a right-handed axial
system, and a fortuitous but welcome result is the

positive polarity of all three leads in the scalar presen-
tation of records from normal subjects.

When recording the axial leads in scalar form, a
calibration signal of 1 millivolt should precede and
follow the tracing.

2. Selection of views

The frontal view and the horizontal* view from
above seem to have been generally accepted as stan-

*In the recommendations published in 1967,1 the term transverse
view or transverse plane was preferred over horizontal view.
Although cogent reasons for the use of the former were given, com-
mon usage of the term horizontal view appears so ingrained that the
Committee decided to adopt the latter.
standard although viewing the latter from below has some advantage. There is less agreement on the sagittal view of the vectorcardiogram, and opinions seem to be evenly divided in preference of the left or right sagittal projection. Although the left sagittal view was preferred over the right in the last recommendations, the Committee decided at this time to abstain from a firm recommendation of either sagittal view as long as a common angular scale is used to denote vector directions. The denotation of angles in the various planes is shown in fig. 5 and described in more detail below in par. D2.

Communications would be facilitated if a common method of displaying axial leads and vector loops was adopted. Since both the left and right sagittal views are considered acceptable, the manner in which planar vectorcardiographic projections are mounted in fig. 6 is recommended. Depending on the choice of left or right sagittal plane projection, one of the two display methods shown in the illustration can be used. A minimum of one complete cardiac cycle should be presented in scalar form together with the vectorcardiographic loops, using the same amplifier gain for both displays. A calibration signal similar to that shown in fig. 2 (see Instruments, par. C9) should accompany each recording in order to indicate the magnitude of deflections and the phase coherence between leads.

C. Nomenclature, Scalar
1. The symbols of P, Tp, QRS, T, and U are to be used to represent the deflections or groups of deflections

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**Figure 5**
Recommended angular scales for VCG display in the frontal, left sagittal, right sagittal, and horizontal planes.

**Figure 6**
Recommended display arrangements for scalar axial leads and VCG loops. In panel A the left sagittal view is used; in panel B, the right sagittal view.
encountered in the electrocardiogram. Criteria for the use of these symbols apply to all leads, unipolar and bipolar, normal and abnormal.

2. The P wave is normally the small initial deflection of any cycle and may be positive, negative, diphasic, or (rarely) multiphasic. The level of reference from which its voltage is measured is the level at the end of the T-P or U-P interval. If it displays a single turning point on both sides of its reference level, it is described as diphasic. If the initial turning point is above this level, it is said to be of the plus-minus (+ −) type, and if below, it is said to be of the minus-plus (− +) type.

In bipolar esophageal and intracardiac leads, the P wave will usually be composed of multiple, rapid deflections not unlike the QRS group of leads from the body surface. In unipolar leads from these regions, a diphasic complex is ordinarily obtained, especially from within the atria or from the esophagus proximate to the left atrium. It is recommended that the same symbols and criteria be used as for ventricular depolarization (see par. 5, below) but that the symbol for each atrial deflection be followed by the subscript P: e.g., Q_p, R_p, S_p, R'_p, S'_p, R''_p, S''_p. Further, the level of reference of these deflections is to be the level at the termination of the T-P or U-P interval.

3. The T_p wave, indicating atrial repolarization, may be found in the P-R segment, that part of the trace between the end of the P wave and the beginning of QRS. It usually continues through the QRS interval, although ordinarily masked by the QRS deflections. If discernible in leads from the body surface, it is a shallow deflection usually below but sometimes above its level of reference. In esophageal and intracardiac leads, it is often of larger amplitude and may be multiphasic.

4. In the majority of electrocardiograms, the QRS complex is superimposed on the T_p deflection. For this reason the level of reference from which the voltage of QRS is measured should be at the level at which the first of the QRS components begins. The voltage of an upward QRS deflection is determined by measuring the vertical distance between the upper edge of the trace at the beginning of the QRS interval and the upper edge of the trace at the apex of the deflection. The voltage of a downward deflection is determined by measuring the vertical distance between the lower edge of the trace at the beginning of the QRS interval and the lower edge of the trace at the bottom of the deflection.

Not uncommonly the lower case letters q, r, and s are employed to designate the corresponding components of the QRS complex when they exhibit relatively low amplitude. Such usage is not mandatory but may be valuable in achieving concise notation; e.g., the Rs pattern which is typical for a normal lead V2 and the Rs or qRs pattern which is characteristic of a normal lead V5. Similar application may be made to other leads, including the scalar leads of orthogonal or other types of vectorcardiographic lead systems, standard extremity leads, and esophageal leads.

5. In order to indicate how the QRS complex should be subdivided for the purpose of assigning symbols to its deflections, it should be borne in mind that the first deflection begins at the onset of the QRS interval when the trace first leaves the reference level. From this point the trace rises or falls to a turning point where the direction of its motion is reversed. It may pass through a second and third or even more turning points, causing notches, before crossing to the opposite side of the reference level.* At this crossing, the first deflection ends and the second begins. The second deflection, which has to be opposite in direction to the first, must display one turning point and may display many; it does not end until the trace crosses the reference level for the second time. A deflection which begins at the second crossing and ends at the junction between the end of QRS and the beginning of the ST segment (ST junction or point J, for junction) is sometimes present. No part of the QRS complex which does not cross the reference level should be considered a separate deflection, provided that there is no appreciable upward or downward displacement of the junctional level with respect to the reference level.

For relatively large amplitudes of junctional displacement, it is recommended that all components of the QRS complex, except the terminal deflection, continue to be defined by successive crossings of the original horizontal reference level which is determined by the onset of QRS. The termination of the final deflection coincides with the junctional point. Some applications of this modification of older nomenclature are illustrated in fig. 7.

The earliest QRS deflection which lies above the reference level should be labelled R. Any downward deflection which precedes R should be labelled Q. The first of any downward deflections which may follow R should be labelled S. The first of any upward deflections which may follow S should be labelled R', and the first of any downward deflections which may

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*When the trace is descending, it crosses the reference level at the instant when its lowest margin reaches a position below that which it occupied at the beginning of the QRS level. When the trace is ascending, it crosses the reference level at the instant when its upper margin reaches a position above that which it occupied at the beginning of the QRS interval.
follow R' should be labelled S'. If labelling still later deflections of the QRS group is necessary, the symbols R'', S'', etc., should be used in accordance with the same principles. When R is absent and the QRS complex consists of a single downward deflection, this deflection may be labelled QS, especially when it is believed that an expected R wave is missing because of a disease process such as myocardial infarction.

A deflection is "notched" when it displays more than one turning point on the same side of the reference level. A deflection is "slurred" when it displays a distinct and local thickening on either limb or at its apex, owing to a sudden and pronounced change in the slope of the curve.

When the form of the QRS complex varies from moment to moment because of the effect of respiratory movements on the position of the heart or for some similar reason, the complex selected for classification should be of the type most abundant or, if no type is numerically predominant, by the outline of the complexes which are of intermediate form. Small QRS complexes (largest deflection less than 0.5 millivolt) which display more than three components or multiple slurrings and notchings may be classed as "small and bizarre" or "vibratory."

6. The term "S-T junction" or "J" (RS-T junction) should be used to indicate the point or shoulder which marks the end of the QRS complex, the point where the steep slopes of the QRS deflections are more or less abruptly replaced by the more gradual slopes which precede or comprise the first limb of the T wave. In many electrocardiograms, the S-T junction is followed by a nearly horizontal or gently sloping segment which lies on, above, or below the reference level. It ends with the onset of a more pronounced slope that rises or falls to the maximum deflection of T. The term S-T segment is used for this part of the ventricular complex between J and the manifest onset of T. In many records, defining a distinct point of separation between the S-T segment and the T wave is not possible because a very gradual transition from one to the other may occur. Since the S-T segment represents electrophysiologically an early part of the T deflection and both S-T and T are part of the ventricular repolarization process, a separation has only limited significance.

The reference level for the measurement of the displacement of the S-T junction (point J) should be the P-R segment at the beginning of QRS. The level of reference for measurements of the S-T segment, the T wave, and the U wave should be the level at the termination of the T-P or U-P interval when this can be determined. This may not be possible at very high heart rates, particularly in maximal or sub-maximal exercise tests since the T wave and the succeeding P wave tend to fuse, and a T-P or U-P interval cannot be detected any more. In such cases, the level of reference should be the P-R segment at the beginning of QRS both for the resting electrocardiogram and the recordings at higher heart rates.

7. The term "diphasic T waves" should be applied to those final ventricular deflections which present two distinct turning points, one on each side of the level of reference, as described for the P waves (see par. 2 above).

8. The P-R interval is measured from the beginning of the P wave to the beginning of QRS whether this be represented by a Q wave or an R wave. This interval varies from lead to lead in the same subject. When only single leads, recorded in sequence, are available, the longest P-R interval found in bipolar or unipolar
leads should be regarded as the P-R interval. The longest P-R interval in single leads is not necessarily the correct one. With the increasing usage of multichannel recorders for obtaining simultaneous leads, measuring the P-R interval from the earliest P deflection to the earliest QRS deflection in any one of three leads which are nearly orthogonal is preferred; e.g., leads I, aVF, and V2. Discrepancies between the "longest P-R interval" and the true P-R interval are easy to detect by use of the latter method.

9. The QRS interval is measured from the beginning (Q or R) to the end of the QRS group of deflections. In single-channel recordings, the longest QRS interval found in the bipolar or unipolar leads is regarded as most nearly correct. In multichannel recordings, the earliest and the latest deflections in any one of the simultaneously recorded leads should be used to indicate the limits of the QRS interval. Most nearly orthogonal leads are preferred.

10. The Q-T interval is measured from the beginning of QRS to the end of the T wave. When obtained from single leads, the longest interval found in any lead is regarded as most nearly correct. In multichannel recordings of nearly orthogonal leads, the earliest and latest deflections in any one of the leads give a better indication of the true Q-T interval. Since this interval varies with heart rate, a correction for this variable must be made in comparative studies.

Similar considerations apply to measurements of the Q-U interval which is less frequently used.

D. Nomenclature, Vector

1. Designating the components of the vectorcardiogram as "loops" and using the letters P, QRS, and T to describe the three loops ascribable to the same electrical processes which account for the similarly designated deflections in the scalar electrocardiogram is recommended. If a Tu or U loop is discernible, they should be so designated.

The symbol or abbreviation for the term vectorcardiogram is VCG.

2. Designation of three vectorcardiographic plane projections shall be frontal (xy), sagittal (zy), and horizontal (xz). As indicated earlier, both the left and right sagittal projections shall be acceptable.

The angular scale shown in fig. 5 divides the frontal plane into a lower and upper half. Beginning at the left side of the subject (right side of the observer), inferiorly directed angles are indicated in clockwise fashion from 0° to +180°. Superiorly directed angles in the upper half of the frontal plane scale also begin on the subject's left side with 0° and are continued in counterclockwise fashion up to −180° on the subject's right side. This angular scale is identical with Einthoven's angle alpha.

Both left and right sagittal projections shall have a common angular scale in order to facilitate comparison of data. The anterior direction will be indicated by 0°. In the lower half of the scale, angles in the left sagittal projection will continue in counterclockwise direction up to +180°. Conversely in the right sagittal plane, they will continue in clockwise fashion. Superiorly directed angles shall have a negative sign. Starting again anteriorly at 0°, they will continue clockwise in the left sagittal plane and counterclockwise in the right sagittal plane up to −180°, indicating posterior direction.

For the horizontal plane viewed from above, the scale will begin with 0° at the subject's left side. Posteriorly directed angles will have a positive sign; and anteriorly directed angles, a negative sign. Rightward direction shall be designated by ±180°.

It is recommended that angles in the frontal plane be designated by the symbol F°; in the sagittal plane, by S°; and in the horizontal plane, by H°.

If a spherical coordinate system is used for designating direction and magnitude of spatial vectors, the symbols V° for elevation (latitude), H° for azimuth (longitude), and M° for magnitude are recommended. Azimuth indicates the projection of a vector onto the horizontal plane. It is identical with H° as defined above for this plane. Elevation is the angle between a vector and the horizontal plane. The level of this plane is indicated by 0°. Inferiorly directed angles are positive and may have an elevation from 0° to +90°. Vectors in superior direction are negative, and the scale extends from 0° to −90°. Spherical coordinates may be used for defining the spatial direction and spatial magnitude of vectors.

3. Communications would be facilitated if some of the terms which are frequently used to represent parts or the total of vectorcardiographic loops were more clearly defined and if common symbols were used to denote these terms. The letter A has been found useful for a long time to indicate an integrated value of a force, including its duration as well as magnitude (time integral). The letter has been embellished in a variety of ways by different authors but always to indicate, in reality, a value of all or part of the electromotive forces of the heart as reflected along a lead axis, in a plane, or in three-dimensional space. Such time integrals can be considered as a mean force or vector, and the term "mean vector" should be reserved for time integrals. In the example shown in fig. 8 for QRS, areas above and below the base line are

*M may be regarded as a general symbol which applies to both instantaneous and integrated vectors.
Figure 8

Method for obtaining time integrals of the QRS complex from axial leads x, y, and z, shown on the left. Negative areas are subtracted from positive areas, resulting in one single value for each lead which is expressed in microvolts seconds. The QRSx loop shown on the top right has two maximal QRS vectors of equal amplitude indicating that this parameter is not a unique representation of vector loop direction. On the lower right, a true mean QRSx vector (AQRSx) derived from time integrals of leads x and z is shown together with a half-area QRSx vector obtained by dividing the loop area into two halves. (For further detail, see text.)

determined. Negative areas are subtracted from positive areas resulting in a single value for each lead expressed in microvolts seconds; e.g., AQRSx. When time integrals of two leads are added vectorially, mean vectors are obtained for vectorcardiographic projection planes; e.g., AQRS_{xy} in the frontal, AQRS_{yz} in the sagittal, and AQRS_{xz} in the horizontal plane. A mean spatial vector is obtained by adding three time integrals; e.g., AQRS_{xyz}.

Although time integrals had been recommended for many years for the representation of an average or mean force, their use has never become widespread, since area determinations, when done by hand, are relatively time consuming. The most common vector term to indicate the general direction of a vector loop has been the \textit{maximal vector}. It represents the instantaneous vector with the largest magnitude in a given plane or in three-dimensional space. It should be designated by the symbol Max, followed by an indication of the loop under study and the projection plane used; e.g., Max \( P_{xy} \), Max \( QRS_{xy} \), or Max \( T_{xz} \). As shown in fig. 8, more than one instantaneous vector with equally large magnitude may exist in some vectorcardiograms. Maximal vectors are, therefore, not a unique representation of vector loop direction. Furthermore, it should be realized that maximal vectors in different plane projections do not necessarily occur at the same instant of time.

Another approximation of mean vector loop direction has been based on half-area vectors. In this approach, a vector is determined which bisects the total loop area into halves. When done accurately by planimetry, this method is also time consuming, but in many cases an estimate of the loop area and of the vector which bisects the loop may suffice. Frequently, the half-area vector direction closely approximates the true mean vector direction as shown in fig. 8. Substantial discrepancies between the two vectors may be encountered with intraventricular conduction delays.

For designation of instantaneous voltages or vectors, the time of occurrence should be indicated in seconds followed by the usual capital letters for specific excitatory or recovery events; e.g., \( P \), \( QRS \), \( ST \), or \( T \). These symbols should be followed by a lower case indication of the axial lead or vector projection plane under consideration. For example, 0.03 \( P_x \) indicates the instantaneous voltage 0.03 second after the beginning of atrial excitation, manifest in the transverse axial lead; 0.05 \( QRS_{xy} \) represents the instantaneous vector 0.05 second after onset of \( QRS \) projected onto the frontal plane; 0.04 \( ST_{yz} \) indicates the vector 0.04 second after the end of \( QRS \) (point J) in the sagittal plane projection.

With oscilloscope visualization or recording of the vectorcardiogram in planes or in space, only the P, \( QRS \), and T loops and 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 these letters for referring to portions of the \( QRS \) loop is not sufficiently specific to denote them as \( Q \), \( R \), or \( S \) loops.

\textsuperscript{T}To identify instantaneous vectors in the various projection planes with sufficient accuracy, instantaneous voltages in the scalar component leads of the plane under study must be obtained first, and then these voltages must be added vectorially. When time markings of vector loops are used for identification of instantaneous vectors, substantial errors in timing may occur for the following reasons:

1. The onset of \( QRS \) differs frequently from one lead to another, and the true beginning of ventricular depolarization is indicated only by that axial lead which displays the earliest departure of the trace from the base line;
2. The true onset of \( QRS \) may be perpendicular to the projection plane under study which will prevent it from being displayed in this plane;
3. Time markings in the vicinity of the \( QRS \) onset tend to be spaced very closely. In addition, parts of the \( P \) or \( T \) loop may be superimposed on early and late portions of the \( QRS \) loop. Determination of instantaneous vectors from time markings of vector loop projections, therefore, is inadvisable.
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