Clinical Observations with an Orthogonal Lead System

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The merits of several orthogonal lead systems are being investigated and it is possible that records from one or more of the systems will be incorporated into clinical electrocardiography. Selection of a system for clinical use involves consideration of its accuracy, convenience, and reproducibility of the results it yields. An electrode arrangement termed the "axial" system has recently been described by McFee and Parungno. Based on its design data, the accuracy of this system appears to be comparable to that of systems proposed by Schmitt and Simonson and Frank. In addition, the axial system is reported to be relatively insensitive to exact electrode placement. This characteristic would be an important asset to convenience and reproducibility of results.

Like other proposed lead systems, the axial system requires clinical evaluation. One step in the necessary evaluation is identification in records obtained with the new system of the counterparts of features of known clinical significance from conventional electrocardiographic leads. Such studies may be expected to define the form in which some findings of established importance in conventional leads are reflected by the new system. They may also be expected to identify those items of known significance in the conventional tracing that the new leads do not reflect in easily recognizable form. Finally, such studies may be expected to contribute to definition of the range of normal variation of records obtained with the new electrode arrangement. Similar studies of the Frank electrode system have been reported.

Further steps in the evaluation of a lead system should include additional techniques of recording and analysis in an attempt to identify as much as possible of the information now obtained from conventional electrocardiograms as well as an attempt to obtain still more useful information.

The purpose of the present study was to identify the counterparts of clinically significant items of information from conventional electrocardiograms in leads from the axial lead system. Later studies will be directed at defining the merits of this lead system when used with methods of recording other than ordinary electrocardiographic tracings.

Materials and Methods

Eighty-five subjects with normal electrocardiograms and 104 patients with a variety of electrocardiographic abnormalities were studied. Subjects in the normal group ranged in age from 18 to 75 years and those with abnormal tracings from 27 to 82 years. Electrocardiographic leads reflecting horizontal (X), vertical (Y), and anteroposterior (Z) components of the heart's electrical activity were recorded with use of the axial lead system. Two electrodes on each side of the chest gave X, electrodes on the neck and left leg gave Y, and three electrodes arranged in the form of a triangle on the anterior chest and one on the back gave Z. The electrode triangle on the anterior chest was oriented with its base nearest the subject's feet and was equilateral with the electrode centers 6 cm. from the center of the triangle. The back electrode was located directly behind the center of the chest triangle. The polarity of leads X and Y was comparable to leads I and V5, with upward deflections representing positivity to the left and downward. Upward deflections in lead Z indicated positivity directed posteriorly. For a detailed description of this system and its design data the original publication should be consulted.

A conventional 12-lead electrocardiogram includ-
ng standard limb leads, augmented unipolar limb leads, and precordial leads V₁ through V₄ was obtained on each subject on the same occasion as the axial leads. All leads were recorded consecutively at a paper speed of 25 mm. per second with a conventional electrocardiograph.

The conventional leads were examined and described in terms commonly employed in electrocardiographic interpretation. The specific features known to have clinical importance were listed, and the presence or absence of the counterparts of these findings in the axial system leads was noted. It was recognized that the counterparts of features in a given conventional lead need not always appear in the same axial lead although lead X was most closely related to leads I, aV₁, aV₂, V₃, and V₅, Y to leads II, III, and aV₃, and Z to leads V₁ through V₄. The final basis of comparison was whether the same clinical significance could be inferred from findings in the axial leads as was attached to findings in the conventional tracing. The normal records obtained in this study were not employed to attempt definition of the quantitative range of variation of axial leads. They were, however, used to indicate the qualitative range of normal variation. For example, T waves in axial leads X and Y from subjects with normal conventional tracings were always upright, and those in lead Z were always inverted; so inverted T waves in leads X and Y could be considered counterparts of abnormal inverted T waves in leads I and aV₃ and upright T waves in lead Z could be considered counterparts of abnormal inverted T waves in V₁ through V₄.

Results

P waves. In axial leads obtained from subjects with normal routine electrocardiograms, P waves were upright in leads X and Y in 82 records and were diphasic in lead X in one record, diphasic in Y in one record, and isoelectric in X in one record. In the same records P waves in lead Z were upright in two, diphasic in 20, isoelectric in four, and inverted in 59 records.

There were no definite abnormalities of the P waves among the 104 abnormal conventional tracings. In the axial leads from these patients, P waves were upright in lead X in 102 records, diphasic in one, and isoelectric in two records. In lead Y, P waves were upright in 99 records, diphasic in two, and isoelectric in three. P waves in lead Z were upright in 16, diphasic in 34, isoelectric in 14, and inverted in 40, which represents a greater percentage of upright and diphasic P waves than were found in normal tracings. The significance of this finding is not certain but it is possible that atrial disease was present in some of the patients with abnormal electrocardiograms and that appropriate criteria applied to axial leads may prove useful in recognizing such disease.

QRS complexes. The counterparts of most of the QRS abnormalities in conventional leads could be recognized in axial system leads. Only those findings from the axial leads of patients with abnormal conventional tracings that definitely differed from findings in axial leads from subjects with normal routine tracings were considered counterparts of abnormalities in conventional tracings. These findings cannot be reported quantitatively, since the range of normal variability of leads from the new system has not been established, but the findings can be described qualitatively and illustrated by selected examples. A normal conventional electrocardiogram and axial leads from the same subject are shown in figure 1A.

Right bundle-branch block may represent an especially important test of the ability of an orthogonal lead system to reflect the clinically significant items of information now obtained from the conventional tracing. The RSR' pattern on which this diagnosis is partially based is often present in V₁ or V₂ while this pattern is absent in V₃ and V₄. Eleven tracings in this study showed evidence of right bundle-branch block, and in all instances the counterparts of the items of information on which this diagnosis was based appeared in the axial leads. When an RSR' pattern was present in V₁ and V₂, lead Z always showed a terminal S wave reflecting late excitation directed anteriorly. This finding was present even when leads V₃ and V₄ had no features on which the recognition of right bundle-branch block could be based. A conventional tracing showing right bundle-branch block and axial leads from the same subject are shown in figure 1B.

Eleven conventional electrocardiograms showed pathologic Q waves in one or more
of the precordial leads V₂ through V₄ that were interpreted as evidence of anterior wall myocardial infarction. In axial leads from 10 of these subjects the initial QRS deflection was upward in Z reflecting excitation directed posteriorly, whereas in all axial leads from subjects with normal electrocardiograms, the initial QRS deflection was downward in that lead. Absence of the normal Q wave in Z was not observed in any of the abnormalities studied other than anterior wall infarction. A conventional tracing showing evidence of anterior wall infarction and axial leads from the same patient showing absence of Q waves in lead Z are shown in figure 2A. One conventional tracing showed deep QS waves in V₁ and V₂ and small Q waves in V₃ and V₄.

Axial leads from this patient showed a normal Q wave in lead Z and no apparent differences permitting recognition of myocardial infarction between the QRS complexes in leads X and Y as compared to those from subjects with normal electrocardiograms. The records of this patient are shown in figure 2B.

Fourteen conventional tracings showed pathologic Q waves in leads II, III, and aVF considered to be evidence of infarction involving the diaphragmatic cardiac wall. In axial leads from these same patients, comparable Q waves were present in lead Y in all cases.

One patient had electrocardiographic evidence of infarction involving the lateral wall only, and three others had evidence of infarction involving this wall as well as the anterior

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**Figure 1**

A. A normal 12-lead electrocardiogram and leads X, Y, and Z recorded with the axial lead system on the same subject. B. A conventional tracing with findings characteristic of complete right bundle-branch block. The counterparts of these findings are present in leads from the axial system and include wide deep S waves in lead X comparable to those in leads I, aV₁, V₅₅, and V₆. There is also a terminal S wave in lead Z which is the counterpart of the R' wave in leads V₁ and V₂.
or inferior wall. Wide Q waves in leads I, aV₁, V₅, and V₆ were present in the electrocardiograms of these patients, and Q waves of similar duration were present in lead X obtained with the axial lead system.

The electrocardiogram of one patient showed small Q waves in V₂ through V₄ and also large R waves in V₂ and V₃. The significance of these findings was uncertain but infarction involving the anterior and posterior cardiac walls was one possible explanation. The Z leads from this patient showed the counterparts of these findings in an initial small R wave and a deep S wave, which were also compatible with infarction in the sites named.

Three electrocardiograms showed evidence of complete left bundle-branch block and, in all, the form of QRS complexes in lead X was similar to that in lead I and that in Y was similar to that in aV₁. Lead Z showed initial Q waves and large R waves corresponding to R waves and deep S waves in V₁ through V₄. Two of the conventional tracings had Q waves in lead I suggestive of septal infarction in the presence of the conduction disorder, and

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**Figure 2**

A. A conventional electrocardiogram with features suggestive of anterior wall myocardial infarction. Axial leads from the same patient show complete absence of the normal Q wave in lead Z, which is the counterpart of the pathologic Q waves in leads V₁ through V₄. B. Also a conventional electrocardiogram with features suggestive of anterior wall infarction including QS deflections in leads V₁ and V₂, and small Q waves in V₃ and V₄. Axial leads from this patient do not show counterparts of the QRS abnormalities in conventional leads that permit the diagnosis of myocardial infarction. Lead Z shows a normal Q wave reflecting initial ventricular excitation directed anteriorly.
comparable Q waves were present in lead X from the triaxial system.

Eleven routine tracings showed QRS abnormalities that were interpreted as evidence of right ventricular enlargement, and 10 showed evidence of left ventricular enlargement. These records presented a special problem with respect to identifying the counterparts of QRS abnormalities in axial leads, since identification of the abnormalities in the routine tracings is partially based on quantitative criteria. Identification of the counterparts of these abnormalities thus becomes dependent on knowing quantitative details of the axial leads. As an example, peak amplitude of the R wave in lead Z in the present series of normal records had a mean value of .73 mv., whereas that of the 11 records from patients whose conventional tracings showed evidence of left ventricular enlargement was 1.3 mv. The present series of normal records is too small, however, to establish reliable

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**Figure 3**

A. A conventional tracing in which T waves are low in lead I and represent an abnormality by conventional standards of interpretation. The counterpart of this finding does not appear in axial leads, with T waves being normally upright in leads X and Y and inverted in lead Z. The conventional tracing also shows large R waves in leads V1 and V2 suggestive of right ventricular enlargement. Lead Z from the axial system shows small R waves, which is the probable counterpart of the QRS abnormalities in V1 and V2, but as described in the text, the identification of chamber enlargement from axial leads will require quantitative definition of the range of normal variation. B. A conventional tracing in which T waves are of low amplitude in V1 through V4 but include a positive component in V5 through V6. Axial lead Z shows an abnormal upright T wave, which is not the counterpart of the biphasic T waves in precordial leads. Other abnormalities of the S-T segment and the T wave in the conventional tracing are represented by recognizable counterparts in the axial leads.
quantitative criteria for the variability of axial leads, so that further attempts to identify this category of QRS abnormalities in axial leads were not made.

All but six of the conventional tracings considered to have abnormal QRS complexes also had abnormal S-T segments or T waves. These together with other tracings that showed abnormalities of only the S-T segments or T waves constituted a group of 99 records. Axial leads from all but two of these subjects showed recognizable abnormalities of the S-T segments or the T waves. In most of these records the counterparts of all individual abnormalities in conventional leads could be identified but there were some exceptions which will be described.

One record had normal T waves in all precordial leads but abnormally low or inverted T waves in leads II, III, and aV_{F}. The axial leads were also abnormal but the specific findings appeared in both lead Y, where T waves were isoelectric, and lead Z, where T waves were diphasic.

One record showed T-wave inversion in leads V_{3} and V_{4} but the polarity of T waves in lead Z was normal. The axial leads were recognizably abnormal, however, on the basis of isoelectric T waves in lead X corresponding to similar T waves in leads I, aV_{L}, V_{5}, and V_{6}.

In one record leads V_{1} and V_{2} showed inverted T waves, which is a normal variant, and T waves in V_{3} and V_{4} were normally upright. Lead Z from this subject showed abnormal upright T waves. Both the conventional and axial records of this subject were recognizably abnormal on the basis of other findings, namely, S-T depression in II, III, and aV_{F} and similar depression in lead Y.

One record showed definite abnormalities of the T waves in V_{3} and V_{4} in which these waves were diphasic but T waves in lead Z were normally inverted. In this record T waves were normal in lead I, but were diphasic in lead X. Another record showed normal upright T waves in leads V_{2} through V_{4}, but abnormal upright T waves in lead Z. The conventional tracing was itself abnormal on the basis of inverted T waves in leads II, III, aV_{F}, and displacement of S-T segments; these abnormalities had specific counterparts in the axial leads. This record is shown in figure 3B. There appeared to be instances in which the same information was reflected in both axial and conventional leads but not in the leads from the two systems that are usually most closely related.

In one instance T waves were clearly inverted in leads II and aV_{F}. T waves were also abnormal in lead Y but were isoelectric rather than inverted. In the same record T waves were inverted in leads I and V_{4} through V_{6} and were diphasic in lead X.

In two records T waves in lead I were low and abnormal by conventional standards of electrocardiographic interpretation. In these records this was the only T-wave abnormality present. T waves in axial leads were not recognizably abnormal, being upright in leads X and Y and inverted in lead Z. One of these records is shown in figure 3A. It is possible that quantitative criteria for the amplitude of T waves in axial leads might indicate that the T waves in these records were actually abnormal, but such criteria are not yet available. It is also possible that the T-wave "abnormality" in the conventional leads was not significant and that the axial leads provide a more valid assessment of cardiac status than the conventional leads. Neither of these possibilities can be evaluated at present.

**Discussion**

Lead systems that do not depend on representing the body as a simple geometric figure are a significant achievement, but their place in clinical electrocardiography must be defined by clinical studies. It needs to be determined whether orthogonal systems furnish all the clinically useful information now supplied by the conventional 12-lead electrocardiogram and also whether they furnish additional information of clinical importance. The form in which useful information is reflected by the new system also needs definition to determine the most appropriate techniques of display and analysis for use with the system. The present study furnishes information con-
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Concerning the form in which electrocardiographic findings of known clinical significance are reflected by an orthogonal system when the system is used to record simple electrocardiographic leads.

Results indicated that most, but not all, of the clinically significant information from conventional 12-lead electrocardiograms appears in easily recognizable form in three leads from the axial electrode system. It is possible that different technics of display and analysis may show an even greater information content. In a study of another orthogonal system, Pipberger and associates reported that virtually all clinically useful information from conventional electrocardiograms could be recovered from orthogonal leads. In that study a resolver was employed to rotate effectively a lead axis to various positions approximating those of precordial leads, with the finding that the significant features of the actual precordial leads could be recognized in the new leads derived from the orthogonal system.

At present the optimum method of recording and interpreting the electrocardiographic data from orthogonal lead systems has not been determined. A variety of technics including simple electrocardiographic leads, vectorcardiograms, records of magnitude and orientation, and various computer analyses of orthogonal leads are being investigated. The place of orthogonal systems in clinical medicine and the merits of various recording and analysis technics will be defined by such studies.

Summary

Orthogonal electrocardiographic leads of 85 normal and 104 abnormal subjects obtained with a new lead system were examined for the counterparts of clinically significant findings in conventional 12-lead electrocardiograms. Most of the findings judged significant in conventional leads had easily recognizable counterparts in orthogonal leads. Excluding findings suggestive of ventricular enlargement, the conventional tracings of 40 subjects showed QRS abnormalities, and counterparts of these were identified in the orthogonal leads of all but one subject. Counterparts of findings suggesting ventricular enlargement could not be evaluated, since the range of normal variation of orthogonal leads obtained with the system used has not been established in quantitative terms. Conventional records of 99 subjects showed abnormalities of the S-T segments or T waves or both, and recognizable abnormalities of these portions of the curves were present in the orthogonal leads of 97 of the subjects.

References
