A Simplified Method for the Resolution of the Orthogonal Electrocardiogram

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The question as to whether unipolar precordial electrocardiographic leads provide clinical information not contained in a 3-lead orthogonal electrocardiogram remains unanswered. A simple, inexpensive switching-type resolver was designed for the investigation of this problem.

On the basis of extensive investigations, Schmitt,1 and Frank,2 concluded that all electric information available from the heart can be recorded by means of three leads perpendicular to each other. However, some evidence suggests that conventional precordial leads, by recording preferentially from local portions of the heart, may supply additional information not provided by a corrected orthogonal lead system. Schmitt and Simonson3 observed in torso model experiments a typical discrimination ratio of 1:2 for conventional electrocardiographic leads. That is these leads record preferentially from certain regions of the heart. Similar observations have been made by others in clinical and experimental studies.4-7

The theoretical and practical advantages of an orthogonal three-lead electrocardiogram with constancy in lead strength and direction are obvious and have been discussed amply.1-2,8-9 In a recent study from this laboratory9 it was shown that the lead strength and directions of Schmitt's system, and Frank's system to a somewhat lesser degree, approach ideal in normal subjects and in patients with electrocardiographic abnormalities. The question remains, however, whether conventional precordial leads provide significant electric information not contained in the orthogonal 3-lead electrocardiogram. This problem can be studied by comparing the 12-lead electrocardiogram with an orthogonal 3-lead electrocardiogram in a large series of patients with electrocardiographic abnormalities.

No adequate diagnostic criteria for the interpretation of 3-lead electrocardiograms are presently available. Therefore, it is necessary to derive scalar leads from the orthogonal systems that are comparable in direction to the conventional 12 leads. This can be accomplished by the use of a resolver.11 To facilitate investigation of the outlined problem a simple and inexpensive instrument was designed.

Resolvers used in the past11 required sine-cosine potentiometers and additional vacuum tube stages. Brody's axostat,12 needs continuous preamplifier adjustments for each angular step. Helm,13 designed a different type which has the advantage of simplicity, but is limited to one angular step between two or three orthogonal leads respectively. In the resolver described here an attempt was made to combine simplicity in design and operation, versatility in angular choice, and insensitivity to errors introduced by large skin-electrode resistances and capacities.

MATERIALS AND METHODS

Schmitt's SVEC III system was chosen to obtain the three orthogonal leads X, Y, and Z. The connections between the patient and the resolver switch box are shown in figure 1. The resistor network, used for first-order lead corrections, and the fixed attenuators of 75 per cent and 71 per cent, for leads X and Y respectively, are placed inside the box. Reversing switches provide selection of either 0 or 180° phase signals from the X, Y, and Z inputs. A differential output leads to three preamplifiers, one for each lead. Single-ended outputs of the preamplifiers are fed back to the box into the X, Y, and Z resolver switches and also through fixed attenuators to the direct...
Fig. 1. Patient cable for Schmitt's orthogonal SVEC III lead system. Resistors at the left are part of the first-order lead corrections of this system. Resistors at the right are weighting attenuators for leads X and Y. The reverse switches (R) provide selection of different quadrants of each plane. For details of electrode placement on the subject see Schmitt and Simonson.

\[
\begin{align*}
R_1 &= 3.2 \text{ K} \\
R_2 &= 7.0 \text{ K} \\
R_3 &= 12.1 \text{ K} \\
R_4 &= 4.7 \text{ K} \\
R_5 &= 9.7 \text{ K} \\
R_6 &= 13.3 \text{ K}
\end{align*}
\]

Fig. 2. Resistor adding network for the derivation of scalar leads from three basic orthogonal leads. Angular steps of 15° are provided for each of the three planes. Resistor values are indicated on top.
X, Y, and Z outputs. The resolvers are switched attenuators with steps selected to give the sine and cosine of the input voltages. The output of the resolvers are fed to simple adding networks which are in turn connected to the output selector switches (fig. 2). The direct X, Y, and Z outputs are also fed to the output selector switches. Output no. 1 can select only X, Y, or Z signals, whereas 2, 3, and 4 can select in addition to these any of the three resolver outputs.

The two input attenuators (for leads X and Y) before the preamplifiers are designed to have the same input impedance (20 megohms) as the preamplifiers.

For each angular step in a plane the resolvers need to solve the following equations:

- **Frontal plane:**
  \[ XY = \pm X \cos \theta \pm Y \sin \theta \]  

- **Sagittal plane:**
  \[ YZ = \pm Y \cos \theta \pm Z \sin \theta \]  

- **Horizontal plane:**
  \[ XZ = \pm X \cos \theta \pm Z \sin \theta \]  

Angle \( \theta \) indicates the chosen angle in a quadrant of a plane \((0 - 90^\circ)\). The quadrant can be selected by use of the reversing switches for X, Y, and Z. In order to avoid the use of sine-cosine potentiometers, switch attenuators are used to provide six steps of 15° each from 0 to 90°. Values of resistance were selected assuming a 1,000 ohms source impedance (preamplifier output) and a very large load impedance (recorder input, greater than 1 megohm). To solve for the values of the resolver resistors transcendental equations result. Therefore, numerical solutions by means of approximations were used to determine the resistor values to three significant figures. The adding networks of the outputs of the resolvers result in a loss of one-half of the signals. For this reason fixed attenuators of one-half are used for the direct X, Y, and Z outputs to give identical gain for all outputs.
The resolver described combines simplicity and angular versatility. Once the electrodes are applied to the patient, they do not need to be moved to record scalar leads from 33 different directions in three planes. Introduction of equalizing factors or adjustments of preamplifier settings as used in other resolver types are not required. The 20 megohms input impedance renders the influence of skin-electrode resistance and capacity negligible. Helm's statement that an input impedance of 50,000 ohms effectively eliminates "significant" errors appears questionable in the light of reported skin resistance studies.

A multichannel rather than a single-channel resolver was designed since the recording of a time reference lead with the resolved leads increases the accuracy of electrocardiographic correlations. It has been stated that time phase relations are maintained in resolved leads. This holds true only for a given lead and its orthogonal components. However, time correlations from one lead to another are not valid when the compared leads are not recorded simultaneously or with a constant time reference lead.

The resolver described here can be modified for any other corrected orthogonal lead system by changing the resistor network for lead corrections (fig. 1) according to the chosen system. Angular steps of 15° were chosen to obtain leads which are approxi-
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mately comparable in direction to conventional precordial leads. Figure 4 indicates the leads which are taken at present in this laboratory with a representative record. The choice of these leads was influenced mainly by the angular directions generally assumed for the conventional 12-lead electrocardiogram. The proposed resolver is considered mainly as a research tool in order to facilitate the collection of data by independent groups. If the assumption is true that all electric information possibly available from the heart can be obtained using three orthogonal leads, then resolving of leads should become obsolete. In this eventuality, criteria for the interpretation of 3-lead electrocardiograms need to be established. Only the lack of adequate criteria at present makes the use of a resolver necessary in order to provide the electrocardiographer with familiar patterns. Resolved leads represent nothing more than a different display of the basic leads X, Y and Z. Therefore, no basically new information can be expected from resolved leads which is not contained in the three orthogonal leads.

SUMMARY

A simple and inexpensive resolver was designed for the derivation of scalar electrocardiographic leads from an orthogonal lead system in steps of 15° in 3-lead planes. This instrument can be used for the investigation of the problem as to whether the orthogonal 3-lead electrocardiogram provides all the electrical information that can be derived from conventional 12-lead electrocardiogram.

SUMMARIO IN INTERLINGUA

Esseva construite un simple e incostose resolutor pro scalar derivationes electrocardiographic ab un systema orthogon con passos de 15 grados in 3 planos. Iste instrumento pote esser usate pro investigar le problema si le orthogon electrocardiogramma a tres derivationes provide omne le information electric que pote esser obtenite per medio del electrocardiogramma conventional a due-duo derivationes.

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