A New Type of Spatial Vectorcardiograph

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The authors have constructed an apparatus with three vibrators and a half-mirror which indicates a spatial vector as a light spot in three-dimensional space. A new type of spatial vectorcardiograph was produced by attaching a vectorcardiograph to this apparatus. The lead system of Frank and a new coordinate system of the authors were employed, and the observation of the cardiac vector was performed. The cardiac vector was visualized as a locus of the light spot which forms three-dimensional loops in space. The observation and the analysis of the heart vector with determination of the quadrants of the loops were performed in normal individuals and in some clinical cases. It was possible to record the spatial vectorcardiogram by the usual photography or stereophotography and to perform objective analysis. This method may be of some value for clinical and educational purposes.

Theoretically, the electrical activity of the heart is represented by the vector which indicates the magnitude and direction of the excitation of the heart. This vector is actually a three-dimensional vector in a volume conductor of the human body and changes instantaneously during the cardiac cycle. If it is assumed that the original point of this cardiac vector is fixed during the cardiac cycle, it would be expected that the cardiac vector describes a loop in space. In vectorcardiography, the loop of the cardiac cycle is projected on the three planes; namely frontal (X-Y), sagittal (Y-Z) and horizontal (Z-X). However, the complexity of the obtained figure and its correlating time course make it impossible to imagine the original loop of the cardiac cycles. Consequently, a better device has been expected which inscribes the cardiac vector in space with its time course.

The method for recording or visualizing this loop of the cardiac cycle is called spatial vectorcardiography¹ or stereocardiography. In this paper, a new type of spatial vectorcardiograph is reported which is convenient for clinical use. The

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clinical application of this method would be published later.

APPARATUS

The principle of this apparatus is shown as a block diagram in Fig. 1. The light beam provided by a conventional light source is reflected by the mirror of the X-vibrator which rotates on the X-axis. The light beam reflected by the X-mirror is, in turn, reflected by the second mirror of the Y-vibrator, which rotates on the Y-axis. The X-axis is devised to make a right angle with the Y-axis. The Y-mirror is rectangular in shape and rotates on its major axis.

The light beam reflected by the Y-mirror is then projected on the screen of the Z-vibrator, which moves back and forth along the Z-axis. The light spot on the Z-screen produces a complete three-dimensional movement. However, it was found that the stereoscopical feeling was greatly disturbed by the fact that the moving screen itself was visible.

But this difficulty was improved by introducing a half-mirror and a dark box with an observing window. Furthermore, three illuminated bars set on the opposite side of the half-mirror helped to observe a three-dimensional orthogonal co-ordinate and to analyze the movements of the light spot quantitatively.

The maximum deflections of the mirrors and the screen were ±25 mm and ±20 mm, respectively.

In this method, some error by the tangential distortion was inevitable. But the sum of the errors was estimated to be less than ±10%.

The X- and Y-mirrors had relatively good frequency response but the Z-screen showed a poor frequency response. Consequently, the overall frequency characteristics were limited by the frequency response of the Z-screen, and its upper
limit was 25 cps.

**LEAD SYSTEM**

The lead system of Frank\(^2\,^3\) was accepted in this experiment. Three components of the cardiac electrical potential, Vx, Vy and Vz, were gained from a usual vectorcardiograph, and were amplified and supplied to each vibrator.

The axes and their polarities were determined as follows (Fig. 2); Y-axis upper (-) to lower (+), X-axis left (+) to right (-), and Z-axis front (+) to back (-). The cardiac vector was observed from the left, upper and anterior direction, which had been found to be the most convenient direction for observation.

The quadrants were nominated as follows. Below the horizontal plane; that surrounded by X (+), Y (+) and Z (+) is the first quadrant, and the second, third and fourth quadrants lie in order counter-clockwise around the Y-axis. Above the horizontal plane; the fifth, sixth, seventh and eighth quadrants are situated on the first, second, third and fourth quadrants, respectively. It was found that the gross interpretation of the spatial vectorcardiogram was feasible by the estimation of the quadrants of the vector.

**RESULTS**

Calibration was given by supplying 1 mV calibration voltage separately on each axis. The amplifier sensitivities were adjusted to be equal on the three axes. Fig. 3 shows the deflection on the X-axis by 1 mV calibration voltage.

**Normal spatial vectorcardiogram**

A usual vectorcardiogram of a normal individual is shown in Fig. 4, A.
Fig. 3. Deflection of 1 mV calibration voltage on X-axis. Photographs of spatial vectorcardiograph in the following figures were retouched.

Fig. 4. Spatial vectorcardiogram of normal male (B). F, H and S in A represent frontal, horizontal and sagittal plane vectorcardiograms, respectively.

Photograph of the spatial vectorcardiogram by the spatial vectorcardiography in the same individual is shown in B. The QRS vector was oriented initially to
the first and then to the second quadrant, and finally the loop was closed. The T loop was inscribed in the first quadrant.

*Vertical heart*

A usual vectorcardiogram and the photograph of the spatial vectorcardiogram of a normal individual with vertical heart are shown in Fig. 5, A and B, respectively. The QRS vector was oriented initially along the X-axis to the first quadrant, then to the second, and next to the sixth quadrant near the sagittal plane. The T loop appeared in the first quadrant.

*Right ventricular hypertrophy*

Fig. 6, B shows a spatial vectorcardiogram of typical right ventricular hypertrophy. The QRS vector, after passing the first quadrant, deflected to the fourth quadrant and finally to the seventh quadrant.

*Congenital heart disease*

This case was clinically suspected of bilateral ventricular hypertrophy accompanied with a congenital heart disease (ventricular septal defect). Fig. 7 shows the QRS loop oriented along the X-axis. Small deflection along the Z-axis was noticed, suggesting that the sum of the anterior and posterior components of the cardiac electric potential was nearly zero in this case.
Fig. 6. Spatial vectorcardiogram of right ventricular hypertrophy in a 22-year-old female (B). F, H and S in A represent frontal, horizontal and sagittal plane vectorcardiograms, respectively.

Fig. 7. Spatial vectorcardiogram of congenital heart disease (ventricular septal defect) in a six-year-old male (B). F, H and S in A represent frontal, horizontal and sagittal plane vectorcardiograms, respectively.
Fig. 8. Spatial vectorcardiogram of anterior wall infarction in a 56-year-old male (B). F, H and S in A represent frontal, horizontal and sagittal plane vectorcardiograms, respectively.

Anterior wall infarction

Fig. 8 was taken from a patient with anterior wall infarction. As shown in Fig. 8, B, the QRS loop was not inscribed in the frontal quadrants, namely the first, fourth, fifth and eighth quadrants, but it was oriented to the third and seventh quadrants. The angle between the QRS loop and the T loop of about 90 degrees was visualized. Simplicity of the spatial vectorcardiogram compared to usual vectorcardiogram was clearly shown in this case.

DISCUSSION

There are three main methods for analysis of cardiac vector: methods for analyzing its components one-dimensionally, two-dimensionally or three-dimensionally. The usual scalar electrocardiography is the method of recording the cardiac vector in several one-dimensional traces. Although each trace is relatively simple, the interpretation of the whole record becomes more complex and difficult as the number of the leads is increased. And a considerable experience is needed for accurate interpretations.

The usual vectorcardiography is the method of recording the two-dimensional loops. However, in spite of the improved theoretical bases, it is still unsatisfactory
for the purpose of understanding the cardiac vector.

The spatial vectorcardiography by our device is advantageous in the three-dimensional visualization of the locus of the cardiac vector. Vector analysis by this spatial vectorcardiograph with the lead system of Frank revealed the following results.

In normal subjects (Figs. 4 and 5), both the QRS and the T loops were oriented in the first, second, fifth and sixth quadrants. Axis deviation was also shown. In Fig. 6, right ventricular hypertrophy was understood from the axis deviation and from the former concepts by usual vectorcardiography. In Fig. 7, the whole vector of bilateral ventricular hypertrophy was oriented along the X-axis, suggesting the cardiac contour. In Fig. 8, the record of anterior wall infarction was more simple in the spatial vectorcardiogram than in the usual vectorcardiogram. The former corresponds well to the calculated figure by Sano with a computer on an anterior wall infarction case.

Thus the spatial vectorcardiograph provides a complete three-dimensional display of the cardiac vector and is valuable for understanding and interpretation of the electrical activity of the heart.

The usefulness of this spatial vectorcardiography should be studied further in both clinical and educational purposes.

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References