Comparison of the Lead Vectors of Five Different Vectorcardiographic Systems

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SINCE 1946, when BURGER and VAN MILAAN¹⁾ proposed the concept of the lead vector, other investigators, such as MCFEE and JOHNSTON²⁾, FRANK³⁾, and SCHMITT⁴⁾, have proposed their concepts, all of which are fundamentally the same as that of BURGER and VAN MILAAN. These various concepts have provided measures for determining the relation of the potential difference between two arbitrary points on the surface of the body with the heart vector. Through these concepts, several investigators⁸⁻¹¹⁾ have devised so-called "corrected orthogonal VCG lead systems" to give the VCGs with the least deformation*, and they have carried out comparisons of the deformation of the various VCG or ECG lead systems⁴⁻⁷⁾. It is well known, however, that the lead vectors, themselves, vary in magnitude and direction with several factors, such as the shape of the conductor, the inhomogeneity in the electric conductivity, the location of the electromotive force of the heart and the location of the lead-point. Another important bearing is that most of the corrected orthogonal lead systems have been devised using the values of the lead vectors measured from a torso model of an American, whose physical constitution is different from that of the Japanese. Therefore, it is necessary to determine whether these corrected orthogonal lead systems can give the VCGs with least deformation, as reported by the proposers, when they are applied to the Japanese.

In the present paper, two healthy Japanese male adults were selected. From them, two plaster torso models were made. One (Model A, Fig. 1) has a physical constitution comparable to that of an American. The other (Model B, Fig. 1) has a physical constitution of an average Japanese adult male. Using these two torso models, each of a different physical constitution, the lead vectors of the various VCG lead systems were measured. From these measurements, the effects of the differences in the physical constitutions upon the lead vectors of these VCG lead systems were determined. At the same time, the features of the deformation of each VCG lead system were investigated.

METHOD

Measurements of the lead vectors were performed for FRANK's⁸⁾, SVEC III⁹⁾, MCFEE-PARUNGAO (MCFEE)¹⁰⁾, and Polygraph III (P III)¹¹⁾ VCG lead systems. For comparison, GRISHMAN's lead system¹²⁾ was selected for the measurement of the lead vectors.

On the inner surface wall of the plaster torso model, 44 lead-points for the five lead systems were selected, and to each lead-point a silver electrode, with a diameter of 9.0 mm, was affixed. The electrodes of each lead system were connected individually through the given networks. The torso was then filled with tap water. As shown in Fig. 1, nine points were selected on a horizontal plane at the level of the lead-point E (center level) of FRANK's lead system, and around the point C. In Model A, point C is 7.5 cm behind and 3.0 cm to the left of the lead-point E.

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* The term "deformation" in this papers refers to non-orthogonality and non-normality of the lead vector and its sensitivity to the dipole location.

In Model B, point C is 6.2 cm behind and 2.0 cm to the left of lead-point E. Nine analogous points were also selected on each of two other horizontal planes. In Model A, one (upper level) is 2.2 cm above, and the second (lower level) is 2.2 cm below the center level. In Model B, one (upper level) is 2.0 cm above, and the second (lower level) is 2.0 cm below the center level. These twenty seven points were considered to be sufficient to cover the volume of the human ventricles. At each of these 27 points, a set of electrodes, consisting of three pairs of component dipoles, oriented along the three anatomical axes (X-, Y-, and Z-axes) and made into a unit, was placed exactly in such a manner so that the direction of each pair of electrodes was parallel with each component axis of the orthogonal coordinate system of the torso model. Then, each component dipole in turn was energized by means of the isolating unit of an electronic stimulator. The energizing current was square pulse in form, 16 volts in voltage, and 40 msec in duration. Whenever the component dipole was ener-

gized, the electric potential difference between each component lead was recorded for each of the five VCG lead systems, and then, the amplitude in each lead was measured.

RESULTS AND CONCLUSIONS

Fig. 2A demonstrates the relative magnitude of the deflection in the three anatomical axes leads of FRANK's lead system, which was obtained when each of the three component dipoles was energized, in turn, at each of the 27 points. Fig. 2B through Fig. 2E demonstrate the data obtained for SVEC III, McFEE's, P III, and GRISHMAN's lead systems, respectively. In each of the three anatomical axes leads, the magnitude of deflection, which is obtained when the orientation of the energized dipole is perpendicular to the direction of the lead axis (for example, Y-axis component and Z-axis

Fig. 1. Shows the location where the component dipole was energized. The figure on the left shows the torso Model A. The figure on the right shows the torso Model B. The letters A, I, M, and E on the surface of each torso model indicate the lead-points of FRANK's lead system. The "center level" is decided so as to fix to the center of the ventricular volume. The "upper level" in Model A is 2.2 cm above the center level, and in Model B is 2.0 cm above the center level. The "lower level" in Model A is 2.2 cm below the center level, and in Model B is 2.0 cm below the center level. At the bottom is shown the horizontal view of each torso model, transversed at the center level. The letter C and the numbers 1 to 8 show the points where the component dipole was located. These nine points are on the same level. In Model A, point C was selected at 7.5 cm behind, and 3.0 cm to the left of the lead-point E of FRANK's lead system. In Model B, point C was selected 6.2 cm behind and 2.0 cm to the left of the lead-point E of FRANK's lead system.

component in X-axis lead), is represented by percentage to the magnitude of the relevant axis component under measurement. This is termed “% disturbing coefficient”. The white bars represent the results obtained from Model A, and the black bars represent those from Model B. The letter C and the numbers 1 to 8 represent the nine locations of the points where the dipole was energized, as shown in Fig. 1.

Tables I and II demonstrate the mean and the standard deviation of the experimental results at the 27 points. The calculation of the mean and the standard deviation was performed for each of the five VCG lead systems. Each figure in each column represents the re-

lative amplitude of deflection in each of the three anatomical axes leads that was observed when each component dipole was energized. The figures with % represent the % disturbing coefficients mentioned above. The orientation of the dipole is shown at the top of each column. The figures in each of the rows (X, Y, and Z), therefore, represent the component values, relative not absolute, of the lead vector for each anatomical axis lead X, Y, or Z. Table I shows the data obtained from Model A. Table II shows the data obtained from Model B.

In an orthogonal VCG lead system, the lead vectors of the three anatomical axes leads are parallel to the corresponding anatomical lead

Fig. 2A. Demonstrates the relative magnitude of the deflection in the three anatomical axes leads (X-, Y-, and Z-axes leads) of FRANK's lead system, which was obtained when each of the three component dipoles was energized in turn at each of the 27 points. In each lead, the magnitude of deflection, which was obtained when the orientation of the energized dipole was perpendicular to the direction of the lead axis under measurement (for example, Y-axis component and Z-axis component in X-axis lead), is represented by percentage to the magnitude of the relevant axis component under measurement (X-axis component in X-axis lead); the % disturbing coefficient. The white bars represent the results obtained from Model A, and the black bars represent the results from Model B. The letter C and the numbers 1 to 8 represent the location of the points where the dipole was energized. Note that the magnitude of the lead vectors of the three anatomical axes leads is relatively constant except in the Z-axis lead in which the magnitude of the Z-axis component of the lead vector increases as the locations of the dipole approaches the point 3.

axis, are mutually perpendicular, are equal in magnitude and are completely independent of the location of the dipole. Therefore, no % disturbing coefficient should be present.

In analyzing the results using the point of view expressed in the previous paragraph, the following can be observed:

1) In each of the X-, Y-, and Z-axis leads of FRANK's, SVEC III, MCFEE's, and P III lead systems, the magnitudes of the lead vectors showed a slight variation as the location of the dipole was changed. There were small differences between the magnitude of the lead vector of the X-, Y-, and Z-axis leads. In addition, the magnitude of the % disturbing coefficients was relatively small in each of the three anatomical axes leads. In GRISHMAN's, however, the magnitude of the lead vector was far greater in the Y-axis lead than in the X- and Z-axis leads. The magnitude of % disturbing coefficients in all of the X-, Y-, and Z-axis leads also was much greater in GRISHMAN's than in the

other four systems. Thus, it may be concluded that FRANK's, SVEC III, MCFEE's, and P III lead systems have less deformations than GRISHMAN's lead system.

2) In the lead vector of the Y-axis, the magnitude of the lead axis component showed the least variation among the three anatomical axes leads. The magnitude of % disturbing coefficient also was small. These results were observed in each of the five VCG lead systems. Thus, the Y-axis lead can be considered generally to be the lead with the least deformation. Viewing the results in further details, it was observed that the deformation in the Y-axis lead of GRISHMAN's system was derived mainly from the existence of the X-axis component, and that the deformation in the Y-axis lead of the other four systems was derived mainly from the existence of the Z-axis component. The Z-axis component in FRANK's system was largest when the dipole was energized at the location corresponding to the dorsal region of

Fig. 2B. Demonstrates the relative magnitude of the lead vectors of the three anatomical axes leads of SVEC III lead system. Note that the Z-axis component of the Z-axis lead vector decreases as the location of the dipole approaches the point 3. Except for the Z-axis, the magnitude of the lead vector is almost constant as the location of the dipole is changed. The % disturbing coefficients are small except for the X-axis component in the Z-axis lead vector.

Fig. 2C. Demonstrates the relative magnitude of the lead vectors of the three anatomical axes leads of McFEE's lead system. Note that a good resemblance can be seen throughout the three anatomical axes leads between FRANK's and McFEE's lead systems.

Fig. 2D. Demonstrates the relative magnitude of the lead vectors of the three anatomical axes leads of P III lead system. Note that an excellent resemblance can be observed throughout the three anatomical axes leads between FRANK's and P III lead systems.

the heart (points 5, 6, and 7, Fig. 1). The existence of the Z-axis component in the Y-axis lead vector of FRANK's lead system may be attributed to the effects of the electromotive force of the heart upon electrode M of FRANK's, which is located on the back.

3) In the lead vector of the X-axis lead, each of the five lead systems showed deformations derived mainly from the existence of the Y-axis component. Nevertheless, as a whole, the X-axis lead may be considered to be the second best lead with respect to the deformation. Viewing the results in further details, it was observed that the value of % disturbing coefficient in the Y- and Z-axis components of the X-axis lead vector was considerably larger in GRISHMAN's than in the four other systems. It was also observed that the magnitude of the X-axis components of FRANK's and P III lead systems increased slightly when the dipole was energized at the location corresponding to the left half region of the heart (points 1, 7, and 8 in Fig. 1). This slight increase in the magnitude

of the X-axis component may be attributed to the insufficiency of these two systems for cancelling the proximity effects of the electromotive force of the heart upon the electrodes located on the left side of the chest.

4) As to the lead vector of the Z-axis lead, all five lead systems showed considerable amounts of variation in magnitude of the Z-axis component as the location of the dipole was changed. All five systems also showed considerably large values of % disturbing coefficients in both the X- and Y-axis components. Thus, with respect to deformation, the Z-axis lead may be considered to be the most problematic. It was observed that the magnitudes of the Z-axis component of the lead vector in FRANK's, P III, and MCFEE's lead systems increased as the locations of the dipoles approached the electrode E of FRANK's lead system (point 3, Fig. 1), whereas in the SVEC III lead system, the magnitude of the Z-axis component decreased.

5) Throughout the three anatomical axes

Fig. 2E. Demonstrates the relative magnitude of the lead vector of the three anatomical axes lead of GRISHMAN's lead system. Note that the magnitude of the lead axis component of the lead vector is much greater in Y-axis lead than in the X- and Z-axis leads. The % disturbing coefficients are large, especially in the Z-axis lead.

TABLE I DEMONSTRATES THE MEAN AND STANDARD DEVIATIONS OF THE RELATIVE VALUES OF EACH COMPONENT OF THE LEAD VECTORS OF THE FIVE DIFFERENT VCG LEAD SYSTEMS THAT WERE OBTAINED WHEN EACH OF THE THREE COMPONENT DIPOLES WAS ENERGIZED IN TURN AT EACH OF THE 27 SELECTED POINTS. THE DATA IN THIS TABLE WERE OBTAINED FROM MODEL A. THE FIGURES WITH % REPRESENT THE % DISTURBING COEFFICIENTS

<i>I</i>		<i>FRANK</i>			<i>SVEC III</i>		
<i>II</i>		<i>along X-axis</i>	<i>along Y-axis</i>	<i>along Z-axis</i>	<i>along X-axis</i>	<i>along Y-axis</i>	<i>along Z-axis</i>
	<i>X</i>	94.78 (± 8.16)	8.60% (± 5.82)	8.12% (± 3.02)	72.93 (± 4.26)	3.09% (± 2.64)	1.91% (± 3.21)
<i>III</i>	<i>Y</i>	4.44% (± 2.34)	71.55 (± 2.92)	9.53% (± 4.92)	1.25% (± 1.47)	69.26 (± 2.50)	3.00% (± 2.03)
	<i>Z</i>	8.92% (± 5.16)	13.10% (± 11.71)	97.37 (± 20.15)	10.43% (± 10.68)	2.00% (± 2.33)	67.15 (± 8.38)
<i>I</i>		<i>Mc FEE</i>			<i>Polygraph III</i>		
<i>II</i>		<i>along X-axis</i>	<i>along Y-axis</i>	<i>along Z-axis</i>	<i>along X-axis</i>	<i>along Y-axis</i>	<i>along Z-axis</i>
	<i>X</i>	127.80 (± 5.64)	7.27% (± 3.10)	2.74% (± 3.52)	117.22 (± 11.00)	9.48% (± 5.75)	6.20% (± 5.75)
<i>III</i>	<i>Y</i>	1.58% (± 1.99)	105.90 (± 6.72)	1.69% (± 1.36)	2.79% (± 1.06)	100.78 (± 1.85)	3.67% (± 1.57)
	<i>Z</i>	11.52% (± 9.26)	5.13% (± 4.02)	141.30 (± 19.26)	2.20% (± 3.49)	12.73% (± 12.10)	131.63 (± 26.50)
<i>I</i>		<i>GRISHMAN</i>					
<i>II</i>		<i>along X-axis</i>	<i>along Y-axis</i>	<i>along Z-axis</i>			
	<i>X</i>	17.74 (± 3.73)	16.84% (± 12.49)	7.11% (± 7.11)	() Standard Deviation % : Per cent Disturbing Coefficients <i>I</i> : Lead System <i>II</i> : Orientation of the Dipole <i>III</i> : Lead Axis		
<i>III</i>	<i>Y</i>	12.08% (± 6.07)	85.74 (± 5.40)	1.06% (± 1.44)			
	<i>Z</i>	30.33% (± 17.12)	54.80% (± 31.62)	5.26 (± 1.85)			

leads, a close resemblance in attitude of the lead vectors was observed in McFEE's, FRANK's, and P III lead systems, and especially so in the latter two.

6) In GRISHMAN's, the magnitude of the % disturbing coefficients in each of the X-, Y-, and Z-axis leads became smallest when the dipole was energized at the locations comparatively equidistant from the lead-points (points 3, 4, 5, at each of the three levels in X-axis lead; all nine points at the lower level in Y-axis lead; and points 5, 6, 7 at each of the three levels in the Z-axis lead). In GRISHMAN's lead system, the electrodes of the three bipolar leads are applied to the thorax so as to form three adjoining edges of a cube, assuming the electric center of the heart being at the center of the cube. Such a cubic arrangement between the electrodes and the heart may have been

accomplished when the dipole was energized at the locations comparatively equidistant from the lead-points and thus would be one explanation why the % disturbing coefficients in X-, Y-, and Z-axis leads became smallest.

7) Except for the difference in lead strength, no remarkable differences could be observed between the lead vectors of the five VCG lead systems measured on the two torso models of different physical constitutions. Thus, it may be suggested that these VCG lead systems, in their original networks and electrode locations, can be applied to the Japanese adult without appreciable error.

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TABLE II DEMONSTRATES THE MEAN AND STANDARD DEVIATIONS OF THE RELATIVE VALUES OF EACH COMPONENT OF THE LEAD VECTORS OF THE FIVE DIFFERENT VCG LEAD SYSTEMS THAT WERE OBTAINED WHEN EACH OF THE THREE COMPONENT DIPOLES WAS ENERGIZED IN TURN AT EACH OF THE 27 SELECTED POINTS THE DATA IN THIS TABLE WERE OBTAINED FROM MODEL B. THE FIGURES WITH % REPRESENT THE % DISTURBING COEFFICIENTS

I		FRANK			SVEC III		
II		along X-axis	along Y-axis	along Z-axis	along X-axis	along Y-axis	along Z-axis
	X	108.33 (± 12.28)	9.63% (± 12.08)	0.33% (± 0.67)	79.74 (± 11.75)	6.90% (± 4.00)	3.83% (± 4.91)
III	Y	0.44% (± 1.25)	86.74 (± 8.01)	12.85% (± 6.09)	0.98% (± 1.11)	80.96 (± 6.85)	6.00% (± 2.56)
	Z	2.81% (± 4.21)	10.25% (± 11.53)	111.89 (± 23.15)	13.10% (± 14.87)	0.49% (± 1.14)	64.71 (± 10.46)
I		MC FEE			Polygraph III		
II		along X-axis	along Y-axis	along Z-axis	along X-axis	along Y-axis	along Z-axis
	X	135.80 (± 3.38)	10.60% (± 2.06)	5.32% (± 3.35)	128.60 (± 9.82)	10.00% (± 7.11)	4.98% (± 3.36)
III	Y	5.40% (± 3.44)	121.20 (± 10.10)	3.64% (± 2.34)	1.46% (± 0.98)	112.89 (± 6.68)	3.58% (± 6.91)
	Z	23.90% (± 9.26)	2.61% (± 4.43)	136.60 (± 7.87)	3.71% (± 2.36)	11.40% (± 16.37)	143.90 (± 26.00)
I		GRISHMAN					
II		along X-axis	along Y-axis	along Z-axis			
	X	17.25 (± 4.20)	25.40% (± 20.88)	8.70% (± 7.70)	() Standard Deviation % : Per cent Disturbing Coefficients I : Lead System II : Orientation of the Dipole III : Lead Axis		
III	Y	10.00% (± 5.50)	93.18 (± 9.40)	1.38% (± 1.62)			
	Z	30.20% (± 17.69)	37.80% (± 30.00)	7.52 (± 2.49)			

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