Combined Ventricular Hypertrophy

A Vectorcardiographic Study in Tetralogy of Fallot with Systemic-Pulmonary Anastomosis

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The vectorcardiographic and electrocardiographic criteria for the diagnosis of combined ventricular hypertrophy remain somewhat less well defined than those for isolated hypertrophy of either ventricle. Although several groups have presented vectorcardiographic patterns of combined ventricular hypertrophy, a comprehensive analysis of the spectrum of tracings observed between right and left ventricular hypertrophy has not been reported.

This study was designed to demonstrate such a spectrum by evaluating a group of patients with tetralogy of Fallot, representing isolated right ventricular hypertrophy, before and after undergoing surgical systemic-pulmonary anastomosis. This procedure leads to an increased pulmonary and left ventricular blood flow and results eventually in varying degrees of increase in left ventricular muscle mass. The postoperative vectorcardiographic changes can thus be attributed to the previously less conspicuous left ventricular forces now assuming greater magnitude and altering the predominantly right ventricular vectorcardiographic patterns seen before operation.

In this paper the vectorcardiographic analysis is based primarily upon a study of the morphology of the QRS pattern with emphasis on the spatial orientation of the maximal QRS vector.

Material and Methods

Vectorcardiograms were obtained in 82 unoperated patients with cyanotic tetralogy of Fallot to establish patterns of right ventricular hypertrophy. The ventricular hypertrophy in cyanotic tetralogy of Fallot is accepted as representative of isolated right ventricular hypertrophy with either normal or less than normal left ventricular muscle mass. Postoperative vectorcardiograms were available in 140 patients with tetralogy of Fallot who were treated by the surgical creation of a systemic-pulmonary shunt (Blalock-Taussig or Potts-Smith) from 1 month to 17 years prior to this study. Included in this group are 22 patients who had both preoperative and serial postoperative vectorcardiograms.

In an effort to rank the contribution of the left ventricle to the vectorcardiographic patterns of the postoperative group, an estimate of the magnitude of the surgically created shunt was made for each patient. This estimate was based upon a comparison of the findings before and after surgery with regard to symptomatology, physical signs, chest roentgenograms, catheterization, and angiographic data. The following three

Figure 1

Symbols used to describe the spatial position of QRS vectors within the x, y, z triaxial reference system.
categories were established: (1+) small shunt—cessation of spells and improvement in physical limitation, but only minor improvement of cyanosis; the development of a soft to moderately loud continuous shunt murmur; slight increase in the pulmonary vasculature as seen on roentgenograms and minimal cardiac enlargement; (2+) moderate shunt—definite improvement in cyanosis and exercise tolerance; development of a loud continuous murmur and prominent peripheral pulses; increased heart size and pulmonary vasculature on roentgenograms; (3+) large shunt—improvement of exercise tolerance over preoperative status but often with easy fatiguing; onset of borderline or frank congestive heart failure; disappearance of most or all of the cyanosis; development of a loud continuous murmur except in the presence of severe pulmonary hypertension when only a systolic murmur may be present; appearance of a hyperdynamic precordial impulse and bounding peripheral pulses; development of marked cardiomegaly and increased pulmonary vascularity as seen in roentgenograms.

The vectorcardiograms were obtained with the Sanborn Viso-Scope with use of the corrected lead system devised by Frank.5 The oscilloscope patterns were photographed on 35-mm. film and enlarged prints (20 X) were used for spatial analysis. Since each plane was photographed separately, complete three-dimensional agreement of the loops could not always be achieved because of respiratory variations, which are difficult to control in infants and children.

The vectorcardiographic nomenclature used to indicate spatial orientation in this study is illustrated in figure 1. The capital letters R (right),

Figure 2

A. Typical vectorcardiogram of right ventricular hypertrophy in unoperated tetralogy of Fallot, illustrating the maximal spatial QRS vector, RAI. B. Vectorcardiogram of a variant form of right ventricular hypertrophy in tetralogy of Fallot, illustrating that the maximal spatial QRS vector, RAI, is not projected on the horizontal plane as the maximal planar QRS vector. C. Vectorcardiogram in postoperative tetralogy of Fallot illustrating a combined ventricular hypertrophy pattern with two maximal spatial QRS vectors, RPI and LAI (pattern RPI • LAI). D. Vectorcardiogram in postoperative tetralogy of Fallot illustrating a pattern of combined ventricular hypertrophy with marked left ventricular potentials with only one maximal spatial QRS vector, LPI. Again as in 2B, the projection of the maximal spatial QRS vector is not clearly evident from the horizontal plane.

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L (left), A (anterior), P (posterior), S (superior and I (inferior) represent the conventional spatial positions. The small letters r, l, a, p, s, and i are used to describe the position of other than maximal vectors. Whenever the spatial vector is perpendicular to any of the three axes (x, y, z) its projection is essentially zero on this axis and the symbols x°, y°, and z° are consequently used.

Three symbols are necessary to characterize the spatial orientation of a point within the x, y, z triaxial reference system. Thus, in figure 2A and 2B, the maximal spatial QRS vector represented by the large arrow points right, anteriorly, and inferioaly and is therefore designated RAI. In figure 2D the single maximal spatial vector, LPI, is oriented to the left, posteriorly, and inferiorly. With this nomenclature 26 distinct spatial positions can be defined within the x, y, z triaxial reference system and 19 of these are illustrated in figure 1.

The spatial orientation of the maximal QRS vector, a feature which is prominent and relatively easy to define, was selected to characterize the spatial QRS loop. This three-dimensional presentation of the maximal QRS vector is derived from the three planar projections as shown in figure 2. Selection of the spatial maximal vector from two planes can be erroneous in loops where this vector is not well projected on all three planes. The maximal vector for the horizontal plane in figure 2B is directed leftward and anteriorly, but spatial analysis indicates that the maximal vector is oriented rightward, RAI. Similarly in figure 2D, the horizontal plane fails to demonstrate the projection of the maximal spatial vector (LPI) into the left posterior quadrant. In such cases the formula \( SM = \sqrt{x^2 + y^2 + z^2} \) should be used to determine the spatial magnitude (SM) of the vectors in question from the projections on the x, y, z axes.

In some vectorcardiographic patterns the spatial loop cannot be adequately characterized by a single maximal spatial vector, since a second prominent vector with almost equal magnitude is present with a considerably different spatial orientation. For the purposes of our analysis a second maximal vector is designated only if it lies outside the spatial quadrant of the first maximal vector and if it has a spatial magnitude of at least 80 per cent of the other maximal vector (figure 2C, RPI . LAI).

**Results**

Eighty-two unoperated patients (age 1 day to 18 years) diagnosed as cyanotic tetralogy of Fallot served to establish vectorcardiographic patterns of right ventricular hypertrophy, as shown in figure 3. Fifty-two per cent of the patients in this group had an RAI pattern which is considered to be a vectorcardiographic representation of isolated severe right ventricular hypertrophy. Variant forms RAY°, Rz°I, and x°AI are included in this group but are not shown separately in figure 3.

In clinically less severe cases (48 per cent), various patterns other than RAI were present showing considerable overlap with vectorcardiograms of patients with small operative shunts. This group is presumed to have greater left ventricular potentials than the RAI group but without autopsy examination it is difficult to determine if the left ventricular mass is nearly normal, normal, or possibly slightly increased.

Vectorcardiograms were obtained in 140 patients with tetralogy of Fallot from 1 week to 15 years after the creation of a systemic-pulmonary shunt. In figure 3 the variability of left ventricular hypertrophy in postoperative tracings is shown and compared with patterns of unoperated patients. The postoperative vectorcardiographic manifestation of left ventricular potentials is a reflection of both the

![Figure 3](http://circ.ahajournals.org/)

*Graph illustrating the distribution of vectorcardiographic patterns in unoperated (82) and operated (140) patients with tetralogy of Fallot. The vectorcardiographic patterns are arranged to show the progression from isolated right ventricular hypertrophy, RAI, to forms with marked left ventricular hypertrophy, Lz°I or LPI. The functional left ventricular overload has been estimated for each postoperative patient from the volume of the estimated systemic-pulmonary shunt (1+, 2+, 3+).*
Figure 4
Transformation from acyanotic (RPI • LAI) to cyanotic (rai • LAI) form of tetralogy. RPI vector has gradually preoperative vectorcardiographic pattern and the size of the surgical shunt. There is a leftward progression in the RV:LV ratio in this figure starting with isolated right ventricular hypertrophy (RAI vectorcardiographic pattern) through combined ventricular hypertrophy toward dominant left ventricular hypertrophy (LPI vectorcardiographic pattern). Right ventricular hypertrophy in the latter pattern is suggested by the small terminal rightward vectors (rpi).

In 22 patients serial vectorcardiograms were available to study the progressive changes in the loops (figs. 4 to 7).

Discussion
The typical cyanotic tetralogy of Fallot represents, by definition, right ventricular hypertrophy. The surgical introduction of a systemic-pulmonary anastomosis results in an increase of left ventricular flow work which in turn produces an increase in left ventricular muscle mass. These changes should be reflected in vectorcardiograms following surgery, and postoperative tracings should display the sequence of evolution of combined ventricular hypertrophy patterns from right ventricular hypertrophy. The data suggest that this reshaping of the vectorcardiographic patterns is predictable from the size of the shunt and the preoperative vectorcardiograms, and that some estimate of the degree of left ventricular contribution is possible.

The entire spectrum of combined ventricular hypertrophy patterns is presented in an idealized form in figure 8. The series starts with a typical preoperative vectorcardiographic pattern of tetralogy of Fallot (RAI), where the

rotated anteriorly. Subclavian-pulmonary anastomosis (1+ shunt) at 9 mo. reversed this evolution with increase of LAI vector and posterior rotation of rai vector. Tracing at 2 mo. when the infant was symptom-free, resembles the postoperative (6 mo.) tracing, except for less prominent posterior forces in the latter. This suggests that transformation of patterns in figs. 3 and 8 can be left to right with increasing age or clinical severity or right to left after shunt surgery.
inconspicuous left ventricular potentials are indicated by the small arrow, lai. A systemic-pulmonary shunt of an increasing magnitude brings about changes in the following order. The previously inconspicuous (lai) vectors in the right ventricular hypertrophy pattern (RAI) increase their magnitude until they are equal to the RAI vectors leading to pattern RAI•LAI (fig. 8a). The RAI vectors rotate posteriorly to Rz°I and finally to RPI positions leading to patterns Rz°I•LAI and RPI•LAI (figs. 8b and c). The LAI vectors now rotate posteriorly to Lz°I and then to LPI leading to patterns RPI•Lz°I (fig. 8d) and RPI•LPI (fig. 8e). These patterns characterized by two spatially discordant maximal vectors most likely represent vectorcardiographic expressions of combined ventricular hypertrophy. Finally, with continuing increase in left ventricular muscle mass, the spatial magnitude of the rightward directed vector decreases but remains conspicuous enough to indicate the presence of right ventricular hypertrophy in a combined ventricular hypertrophy pattern with left ventricular preponderance, i.e., pattern rpi•LPI (fig. 8f). An isolated left ventricular hypertrophy pattern LPI ends the series with no significant rightward vectors. Such a complete transformation from isolated right ventricular hypertrophy (RAI) to isolated left ventricular hypertrophy (LPI) has not been seen in any of our cases of typical tetralogy of Fallot followed by serial tracings.

A modification of this sequence is seen in patients with tetralogy of Fallot who have come to surgery with vectorcardiographic patterns without dominant RAI vectors. These follow a similar course of transformation as shown in figure 8 except that the rightward
The vectorcardiographic evolution of unoperated tetralogy of Fallot was followed by means of serial tracings in over 40 patients and without exception there was either stability of the patterns in the older children or a rightward shift of the dominant vector forces in the younger patients. No patient showed a spontaneous leftward shift of these forces or the evolution of combined ventricular hypertrophy patterns from a right ventricular hypertrophy pattern without surgical intervention.

Beregovich et al. have described three vectorcardiographic patterns of combined ventricular hypertrophy in patients with ventricular septal defect. In none of their cases was there a significant rightward directed terminal vector, but this may be related to the difference in the vectorcardiographic system used (Grishman) as well as to fundamental differences.

**Figure 6**
Vectorcardiographic tracings in a severe form of tetralogy. Preoperatively the right ventricular hypertrophy pattern was RAy'. Following a subclavian-pulmonary anastomosis (1+ shunt) the single maximal RAy' vector has rotated inferiorly and is now joined by the increasing LAI vector, indicating an increase in left ventricular potentials resulting in pattern RAI • LAI.
in the anatomic material studied. As far as the direction of maximal spatial QRS vectors is concerned, their types A and B can be related to the spectrum of vectorcardiograms without rightward oriented maximal vectors that we have observed in tetralogy of Fallot with surgical shunts. Their type A represents the LPI pattern, type B the LAI pattern, and type C represents either an Lz°I or LPI pattern but with a left axis deviation and is thus not discussed in our study.

Our material indicates that the electrocardiographic pattern referred to as the Katz-Wachtel sign, later referred to by Sodi-Pallares and Calder and Dack as large equiphasic or diphasic complexes recorded over the midprecordium and signifying combined ventricular hypertrophy, is present in about one third of our postoperative tetralogies. The patterns generating the Katz-Wachtel sign have a significant degree of anterior-posterior orientation and are best represented by forms of combined ventricular hypertrophy with an RPI vector as one of the maximal spatial vectors (e.g., pattern RPI • LAI).

In the small group of combined ventricular hypertrophy patterns in which the vectorcardiograms closely resemble normal patterns (LAI, Lz°I, or LPI) quantitation of the spatial maximal vectors may prove of value in separating normal from abnormal subjects. In our analysis of the normal vectorcardiograms now in progress on 180 subjects aged 2 days to 17 years, the magnitude of the maximal spatial vector did not exceed 2.5 mV (mean maximal spatial vector, 1.4 mV ± 0.4 S. D.).
Summary

An attempt has been made to uncover the vectorcardiographic spectrum of combined ventricular hypertrophy by studying a group of 82 patients with cyanotic tetralogy of Fallot representing right ventricular hypertrophy with normal or less than normal left ventricular muscle mass and 140 patients with tetralogy of Fallot and surgically created systemic-pulmonary shunts representing right ventricular hypertrophy combined with varying degrees of increased left ventricular muscle mass.

An analysis of the spatial orientation of the maximal QRS vectors has demonstrated a continuum of vectorcardiographic patterns. These extend starting with severe right ventricular hypertrophy through a series of ventricular hypertrophy patterns representing right ventricular hypertrophy with progressively increasing left ventricular potentials toward dominant left ventricular hypertrophy patterns of combined ventricular hypertrophy. An estimate of the relative contribution of the two ventricles to a given vectorcardiographic pattern of combined ventricular hypertrophy is possible by analysis of the direction of maximal spatial QRS vectors.

Figure 8

Schematic presentation of the evolution of vectorcardiographic pattern RAI following systemic-pulmonary anastomosis in tetralogy of Fallot based upon observation in 140 operated patients. The sequence represents the vectorcardiographic expression of progressively increasing left ventricular potentials reshaping the vectorcardiographic patterns of right ventricular hypertrophy into patterns of combined ventricular hypertrophy. A variant form of this sequence is also frequently seen when the rightward vectors are not prominent and do not constitute a second near maximal spatial vector. The series starts with the right ventricular hypertrophy pattern RAI·lai and progresses through Rz*I·LAI, RPI·LAI, RPI·Lz*I to rpi·LPI.

References


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