Multiple Crystal Cross-Sectional Echocardiography in the Diagnosis of Cyanotic Congenital Heart Disease

By David J. Sahn, M.D., Richard Terry, M.D., Robert O'Rourke, M.D., George Leopold, M.D., and William F. Friedman, M.D.

SUMMARY

A new multiple crystal echocardiographic system was used to assess cross-sectional cardiac anatomy in real time in fifty infants and children with cyanotic heart disease, and the findings were compared to normals. Four standard transducer positions were employed to evaluate sagittal and transverse cardiac cross-sections. Studies in patients with tetralogy of Fallot demonstrated an enlarged aorta overriding the septum with preservation of mitral-aortic continuity. In the absence of pulmonary atresia the main pulmonary artery could be identified in all of these patients. The diagnosis of d-transposition of the great vessels was established by viewing great vessel orientation in transverse section at the second intercostal space and observing a rightward and anteriorly placed great artery. In sagittal projections a retrosternal aorta and mitral-pulmonic continuity was observed. In one patient with d-transposition, apposition in systole of the ventricular septum and anterior leaflet of the mitral valve was identified as the cause of left ventricular outflow tract obstruction. Descriptions are provided of the findings in patients with i-transposition, double outlet right ventricle, and truncus arteriosus. The new multiscan method allows a substantially more precise determination of intra- and extra-cardiac spatial relationships than single crystal techniques. Multiscan echocardiography is safe, widely applicable, and provides clinically important information to assist in the diagnosis and management of infants and children with cyanotic heart disease.

Additional Indexing Words:
Noninvasive Ultrasound Multiscan
Tetralogy of Fallot Transposition of the great arteries Corrected transposition of the great arteries
Truncus arteriosus Double outlet right ventricle

Although multiple causes exist for the presence of cyanosis in infants and young children, arterial desaturation is commonly the result of cardiac malformations in which the great arteries are transposed, or right ventricular outflow tract obstruction exists in association with a ventricular septal defect. Various attempts have been made with single crystal techniques to define the echocardiographic features of both transposition of the great vessels and tetralogy of Fallot. Nevertheless, they only provide a "flashlight beam" section of the heart that may not allow an accurate assessment of the spatial orientation of intra-cardiac structures. Thus, the data provided by single crystal echocardiography in the presence of complex alterations in intra- and extra-cardiac architecture are often difficult to interpret objectively. Fortunately, stop-action cross-sectional B scan imaging which avoids some of these problems is quite difficult to perform accurately and consistently in pediatric patients who do not comply with instructions to remain immobile.

Recently, a multiple crystal ultrasound technique (multiscan) was devised which provides real time, two-dimensional cross-sectional cardiac visualization. This approach greatly facilitates the noninvasive assessment of congenital heart disease since it allows a definition of great vessel orientation, cardiac chamber position, and outflow tract anatomy. The present report details our experience in the use of sagittal and transverse cross-sectional cardiac imaging with the multiscan method in evaluating the common forms of cyanotic cardiac malformations.
Methods

Fifty infants and children with cyanotic or potentially cyanotic heart disease (mean age 22 months; range, 1 day to 13 years) (table 1) were examined using a prototype multiple crystal echocardiographic system designed by Nicholas Bom at Erasmus University in Rotterdam.11-13 Diagnoses were confirmed by standard hemodynamic and biplane cineangiographic techniques in each patient in the study group. The findings in this group were contrasted with those obtained from fifty normal infants and children. Data were retrieved on video tape and super 8 motion picture film from an oscilloscopic monitor. Occasionally, polaroid stills were obtained directly from the oscilloscope (fig. 1). Photographic enlargement of this small format motion picture film accounts for the increased grain and reduction of data seen on most of the illustrative examples accompanying this report. A 4.5 MHz, 20 element transducer was employed in all patients. Cross-sectional cardiac anatomy was evaluated in a systematic manner using two sagittal and two transverse views (figs. 1–4) as follows:

Position 1. Sagittal: Transducer placed vertically along the left sternal border along the heart’s long axis (fig. 1).

Position 2. Transverse: Transducer placed horizontally in the fourth intercostal space just to the left of the sternum (fig. 2).

Position 3. Sagittal: Transducer placed obliquely with the bottom element at the third intercostal space and left sternal border and the top element below the left clavicle (fig. 3).

Position 4. Transverse: Transducer placed horizontally in the second intercostal space (fig. 4).

Real time studies were analyzed independently by two observers for (1) left ventricular and right ventricular dimension and orientation (positions 1 and 2); (2) mitral-aortic and septal-aortic (or mitral-pulmonic and septal-pulmonic) relationships (positions 1 and 2); (3) great vessel orientation and size in the second intercostal space (position 4); and (4) the size and course of the retrosternal anterior great vessel (positions 1 and 3). A preliminary report has appeared concerning the validation of the relationship between echoes and anatomic structures viewed by the multiscan utilizing selective injections of indocyanine green dye and catheter visualization during hemodynamic study in ten patients.14 We have, in the present report, included an illustration (fig. 3 bottom) confirming anatomic landmarks in position 3. Since some of the cross-sections employed in the current study appear rarely in anatomy textbooks and are not those routinely visualized by angiocardiography, validation of structure identification is extremely important. Normal values for echocardiographic dimensions were those obtained previously in our laboratory15 and by others.7

Table 1

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. a. Cyanotic tetralogy of Fallot</td>
<td>15</td>
</tr>
<tr>
<td>with absent pulmonary valve</td>
<td>2</td>
</tr>
<tr>
<td>b. Acranotic tetralogy of Fallot</td>
<td>15</td>
</tr>
<tr>
<td>2. d-Transposition of the great vessels</td>
<td>10</td>
</tr>
<tr>
<td>with ventricular septal defect and pulmonary stenosis</td>
<td>2</td>
</tr>
<tr>
<td>3. Double outlet right ventricle</td>
<td>1</td>
</tr>
<tr>
<td>4. l-transposition of the great vessels</td>
<td>2</td>
</tr>
<tr>
<td>with Ebstein’s malformation of tricuspid valve</td>
<td>1</td>
</tr>
<tr>
<td>5. Truncus arteriosus — type I</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
</tr>
</tbody>
</table>

Cyanotic Heart Disease

Results

Normal Anatomy

Normal cardiac cross-sectional relationships may be summarized as follows:

Position 1 Sagittal. In the long axis sagittal view of

![Figure 1]

Position 1: Normal sagittal cross-section. The top of the transducer (indicated by the asterisk) is superior. The lower panel is a polaroid photograph. Mitral aortic and septal aortic continuity are shown. Ao = aorta; LA = left atrium; SEPT = interventricular septum; AML, AMVL = anterior mitral valve leaflet; PML, PMVL = posterior mitral valve leaflet; LV = left ventricle; RV = right ventricle; RVOT = right ventricular outflow tract; LVPW = left ventricular posterior wall; RVD and LVD represent areas where ventricular dimensions would be measured.
the heart (fig. 1) the right ventricle and right ventricular outflow tract occupy the anterior-superior portion of the section. The septum is seen in continuity with the anterior wall of the aorta. The anterior and posterior walls of the aorta are parallel and the anterior mitral leaflet is a direct, inferior extension of the posterior aortic wall. In some patients, the anchoring of the anterior mitral valve leaflet by its chordae tendineae to the anterior papillary muscle may be visualized. The left atrium is seen posterior to the aorta. The position of the mitral annulus giving rise to the posterior mitral leaflet is visualized at the atrioventricular junction. Inferiorly, from this point, the left ventricular wall sweeps anteriorly towards the cardiac apex.

**Position 2 Transverse.** In this position (fig. 2) a transverse section through the body of the ventricles is obtained at the fourth intercostal space. The tricuspid valve and annulus lie at the most rightward, anterior portion of the cross-section. The right atrium is visualized posteriorly. The interatrial septum is not visualized since it lies in a plane almost parallel to the incident sound energy. Likewise, the ventricular septum is visualized only partially in this view. An oblique section of the right ventricular cavity bounded by the anterior portion of the ventricular septum lies leftward and anterior to the tricuspid valve. The mitral annulus and the anterior mitral leaflet are posterior to the septum and separated from it by the width of the left ventricular outflow tract. The left, posterior portion of the cardiac section is comprised of the posterior mitral leaflet and posterior left ventricular wall. Left and right ventricular dimensions may be measured in this view (fig. 2) and closely correspond to similar measurements obtained in sagittal position 1 (fig. 1). Tilting the transducer superiorly from position 2 scans the left ventricular outflow tract and demonstrates mitral-aortic and septal-aortic continuity (dotted lines, fig. 2).

**Position 3 Sagittal.** In this position the transducer is aligned along the right ventricular outflow tract (fig. 3). The septal leaflet of the tricuspid valve may be seen just below the infundibulum. The right ventricular outflow tract sweeps posteriorly and pulmonary cusp tissue marks the position of the valve. The aorta passes obliquely from left to right and is seen only in partial cross-section.

**Position 4 Transverse.** In this position normal great vessel orientation may be viewed with the transducer in the second intercostal space (fig. 4). The pulmonary artery is to the left of, and anterior to, the aorta. Thus, the pulmonary artery is seen at the bottom of the multispan cross-section. Cusp tissue within this anterior vessel may be found by a slight tilt of the transducer superiorly, whereas cusp tissue within the posterior vessel may be found by tilting the transducer slightly inferiorly.

**Abnormal Anatomy**

**Tetralogy of Fallot**

The major findings in cyanotic tetralogy of Fallot are illustrated in figures 5 and 6 and diagnostic criteria are presented in table 2. The most important feature of this anomaly is observed in sagittal position 1, and consists of a disruption of aortic-septal continuity with the preservation of mitral-aortic continuity (fig. 5). In this view one can appreciate an enlarged ascending aorta which overrides the ventricular septum. Aortic override was visualized in all of the cyanotic patients and in all but two of fifteen patients with tetralogy of Fallot who were acyanotic. In these two patients only a minimal suggestion of this finding existed and it was possible to predict the diagnosis prior to cardiac
catheterization. It should be mentioned that in evaluating a large group of patients with acyanotic forms of congenital heart disease, one patient with an atrial septal defect and a marked right ventricular volume overload had a septum which appeared to be displaced posteriorly from the anterior wall of the aorta in a manner quite similar to that seen in cyanotic tetralogy patients. Thus far, we have seen no other false positives with regard to the echo visualization of aortic override, although initial difficulty in demonstrating septal-aortic continuity was experienced in an additional patient with aortic stenosis and insufficiency in whom the aortic root was greatly dilated.

Additional findings of value using sagittal position 1 and transverse position 2 in each of the cyanotic patients with tetralogy included an increase in the cavity size of the right ventricle and a reduction in left atrial dimension. Right and left ventricular dimensions, as well as left atrial dimensions, were increased in the acyanotic group and also in patients with palliative systemic-pulmonary anastomoses.

Sagittal position 3 (fig. 6 top) and transverse posi-
Table 2

Cyanotic Tetralogy of Fallot (N = 17)

Major criteria
1. Aortic septal overriding with mitral aortic continuity preserved (N = 17)
2. Increased aortic diameter (N = 13)
3. Decreased pulmonary artery size (N = 11)

Minor criteria
1. Increased right ventricular dimension (N = 12)
2. Inability to measure or identify the main pulmonary artery (N = 3)

D-Transposition of the Great Vessels (N = 12)

Major criteria
1. Aorta anterior and to the right of pulmonary artery in the second intercostal space (N = 11)
2. Retrosternal vessel (aorta) found with rightward angulation — ascends without significant posterior sweep (N = 9)
3. Posterior vessel (pulmonary artery) found with leftward angulation with mitral-pulmonic continuity (N = 9)

Minor criteria
1. Good simultaneous visualization of anterior and posterior great vessels ascending in the same plane (N = 7)
2. Increased right ventricular dimension (N = 10)

... (continued)

tion 4 (fig. 6 bottom) allowed identification of the pulmonary artery and assessment of its size unless severe pulmonary hypoplasia existed (3/32 patients). The pulmonary artery was not identified in two ad-
ditional patients who were demonstrated at cardiac catheterization to have Type 1 truncus arteriosus (vide infra). Therefore, in 91% of the tetralogy group the relative size and normal orientation of the pulmonary artery and aorta could be assessed. It was not possible to define accurately the precise site of obstruction since the view of the right ventricular outflow tract in normals often gives the impression of systolic obliteration of the sub-pulmonic region. However, in several tetralogy patients pulmonary cusps tissue was clearly thickened and exhibited poor lateral mobility and an increase in superior-inferior excursion (doming). Aneurysmal dilatation of the main pulmonary artery could be detected in two patients with absence of the pulmonary valve.

Truncus Arteriosus

Two patients with type 1 truncus arteriosus were evaluated. The findings were quite similar to those described for tetralogy of Fallot, although a main pulmonary artery could not be identified in either. In sagittal position 1 both patients showed a marked degree of aortic-septal override, and there were multiple and unusual cusp echoes within the truncal root. We would speculate that this latter finding reflects an abnormal number of cusps of the truncal valve and may, if present, allow the distinction of patients with truncus arteriosus from other patients with pulmonary atresia and a ventricular septal defect ("pseudotruncus").

d-Transposition of the Great Vessels

The major findings in patients with situs solitus and d-transposition of the great vessels are illustrated in figures 7 and 8 and diagnostic criteria appear in table 2. In sagittal position 1 the right ventricle is enlarged (fig. 7). The aorta ascends retrosternally in marked
contrast to the normal posterior sweep of the pulmonary artery. In order to visualize continuity between the anterior mitral leaflet and the semilunar valve of the posterior great artery it is necessary to angle the transducer leftward. Commonly, good simultaneous visualization was achieved of the anterior and posterior great vessels ascending one behind the other in the sagittal plane (fig. 7 top). The most important finding in patients with d-transposition was observed in the transverse position 4 (fig. 8). In this view the anterior great artery was seen to lie to the right of the posterior great artery. Moreover, the course of the two great arteries may be traced from this plane in order to delineate their ventricle of origin. These maneuvers demonstrate that the anterior, rightward vessel (the aorta) originates from the right ventricle while the posterior, leftward vessel (the pulmonary artery) originates from the left ventricle. In the absence of dextrocardia we saw no other situation in which the anterior vessel was to the right. However, we recognize that rare forms of transposition may demonstrate unusual great artery orientation.\textsuperscript{16, 17} While we have not yet studied patients with either a left-sided aortic origin or side-by-side great arteries we would suspect that the long retrosternal course of the anterior aorta in these conditions would be observed clearly in sagittal position 1.

\textbf{Figure 6}

Main pulmonary artery in tetralogy of Fallot is seen in selected frames of an 8 mm motion picture. Top: Position 3 Sagittal. Normal posterior sweep of the small pulmonary artery in tetralogy of Fallot. Bottom: Position 4 Transverse. The small pulmonary artery is in normal position with respect to the aorta, that is, to the left and anterior. Abbreviations as in figure 1.

\textbf{Figure 7}

Top and middle panels: Position 1: Sagittal relationship of the great vessels in d-transposition is shown in a slightly retouched still frame from an 8 mm motion picture. The aorta and pulmonary artery ascend one behind the other. Bottom panel: Position 1 Sagittal: The anteriorly placed aorta ascends retrosternally without a significant posterior sweep. Abbreviations as in figure 1.
In two patients with d-transposition and left ventricular outflow tract obstruction the pulmonary artery was reduced in size. One of these patients had pulmonary valve stenosis and a quite narrowed anulus. The other patient is of particular interest. This seven-month-old infant had a d-transposition and a ventricular septal defect with systemic pressure in both left ventricle and pulmonary artery at first hemodynamic study at age two weeks. At age seven months the pulmonary artery pressure was 16/9 mm Hg with a 62 mm Hg pressure difference between left ventricle and pulmonary artery. The multiscan study at age seven months demonstrated striking septal-anterior mitral leaflet apposition in systole and this finding was confirmed angiographically. Thus, the mechanism of left ventricular outflow tract obstruction in this infant was analogous to that seen in patients with normal great artery orientation and idiopathic hypertrophic subaortic stenosis.18, 19

Double Outlet Right Ventricle

In the one patient studied with double outlet right ventricle we noted that both great vessels arose anteriorly as viewed in sagittal position 1. Transverse position 4 showed side-by-side great arteries with both semilunar valves lying in the same superior-inferior plane. The posterior wall of the leftward great artery (the pulmonary artery) was displaced anteriorly from the mitral annulus. Chesler et al.20 described the single crystal echocardiographic finding of mitral-semilunar valve discontinuity in patients with double outlet right ventricle in whom the posterior great vessel was anteriorly displaced from the mitral anulus. It is important to recognize that discontinuity may also exist in a superior-inferior plane in such patients with partial transposition because of the presence of subpulmonary conal tissue.21, 22 In the patient cited above, mitral-pulmonic discontinuity was present in both the anterior-posterior as well as the superior-inferior relationships. Unfortunately, single crystal echocardiographic reports exist that create confusion concerning the presence of mitral semilunar discontinuity in patients with severe left ventricular dilatation or with anterior displacement of the aortic root, e.g. tetralogy of Fallot.8 Since accurate definition of mitral semilunar relations exists in multicystal sagittal position 1 we believe that erroneous single crystal interpretations may arise from angulation artifacts and are caused by too rapid sweeping of the transducer.

l-Transposition of the Great Vessels

Although the three patients studied with l-transposition of the great arteries were acyanotic, comments about their findings are included, since attention is focused in this report on great artery orientation. In these patients in transverse position 4,

Figure 8

Position 4: Transverse section of transposed great vessels at the second intercostal space. Abnormal great vessel orientation is shown in a still frame from an 8 mm motion picture. The anteriorly placed aorta is now to the right of the posteriorly placed pulmonary artery. Abbreviations as in figure 1.

Figure 9

Position 2: Transverse section in a patient with l-transposition of the great vessels shows displaced side-by-side ventricles and A-V valves. The interventricular septum is not visualized. MV = right-sided mitral valve; TV = left-sided tricuspid valve; LA = left atrium; RA = right atrium; Right-Sided VENT = right-sided morphologic left ventricle; Left-Sided VENT = left-sided morphologic right ventricle.
great vessel orientation appeared to be normal with
the anterior vessel (the aorta) located to the left.
However, a correct diagnosis could be made by trac-
ing both great vessels back to their ventricles of origin
in this plane. The anterior leftward great artery (the
aorta) arose from the anterior leftward portion of the
left-sided ventricle. Further, in sagittal position 1 the
anterior aorta had the long retrosternal sweep referred
to above as characteristic of transposition anomalies.
Moreover, in transverse position 2 both ventricles and
their atrioventricular valves appeared to lie side-by-
side (fig. 9). In these patients the ventricular septum,
like the atrial septum, was in a straight antero-
posterior plane parallel to the incident sound energy
and was, therefore, not visualized. In one of the
patients with l-transposition the left-sided A-V valve
in sagittal position 1 appeared to be displaced in-
finitely in the position expected in Ebstein’s anomaly.
A diagnosis of left-sided Ebstein’s anomaly was con-
firmed at cardiac catheterization.

Discussion

Traditionally, the accurate description of the
anatomic alterations and physiological sequellae of
congenital cardiac malformations has depended upon
cardiac catheterization and selective angiocar-
diography. Since these methods carry greater risks to
newborns and small children than to adults, the
development of accurate, noninvasive methods to
assist in the diagnosis and management of heart dis-
ease is of particular importance in the pediatric age
group.23 As outlined in this report, multiscan echocar-
diography is a new approach that broadens signifi-
cantly the accuracy and applicability of ul-
trasound diagnosis in infants and children. The system
provides instantaneous, two-dimensional cross-
sectional images of the heart in motion.

It is our view that the cross-sectional technique
avoids many of the limitations that arise when single
crystal methods are applied to the complex lesions
that are encountered in pediatric cardiology. Single
crystal techniques to define the anatomy of tetralogy
of Fallot6-8 appear to be capable of identifying aortic
override although identification of the pulmonary
artery is often not possible. Similarly, single crystal
techniques have been employed in attempts to define
the altered anatomy in transposition of the great
arteries.1-6 In this group of patients some investigators
have employed a method that is difficult to standard-
ize whereby the single crystal beam is angled to iden-
tify each great artery.1,2 Other investigators have
utilized the temporal sequence of semilunar valve
closure in efforts to identify the pulmonary artery
irrespective of its ventricular origin.8 The major
limitation with all of these efforts relates to recogniz-
ing the spatial orientation of the single beam and,
therefore, the exact position of the echo-producing
structure. As a result, the standardization of single
crystal techniques is difficult when dealing with
deformed hearts and great reliance must be placed on
individual examiner judgments for accurate diagnosis.
Recently, King and his associates have employed stop-
action, two-dimensional, B-scanning techniques in
order to evaluate the spatial relationships between the
great arteries.5,4 While these efforts result in more
reliable anatomic information, the method is time
consuming and extremely difficult to perform in small
infants. Further, the instrumentation lacks portability,
an important feature if premature and newborn in-
fants are to be evaluated in intensive care nurseries.
Since the multiscan approach avoids all of these
difficulties, we believe that it offers promise to the
noninvasive study of the heart of the infant or child.

It must be appreciated that the illustrations that ac-
company this report are but single frames derived
from real-time motion studies that are visualized best
on an oscilloscope. Furthermore, they have been sub-
jected to photographic enlargement from a small for-
mat motion picture film, except for figure 1 which is
an ECG-gated polaroid print. The use of ECG-gated
polaroid exposures postdated the accumulation of
data from the group of patients discussed in this
report. Even with a polaroid system, it should be
recognized that still pictures are quite difficult to ob-
tain in children with rapid heart rates, and with slow
camera shutter speeds designed to avoid phase in-
terference. Some of the photographs which ac-
company this report have been retouched to a minor
degree for illustrative purposes. Anatomic details are
substantially clearer and structure identification
facilitated greatly by review of the moving images.
The limitations of the system with regard to depth and
gain-related lateral resolution have been described by
Bom et al.12 In small children there are respiratory
variations in the visualization of anterior structures.
Further, portions or all of certain intracardiac struc-
tures, e.g., the interatrial septum, or the interven-
tricular septum in l-transposition, may not be
visualized because their orientation is parallel to the
incident sound energy in specific transducer positions.
Nevertheless, in our experience, the examiner learns
to use the dimension of motion along with his a priori
knowledge of cardiac anatomy and function to form a
mental image superior to that which can be converted
in a static picture, i.e., he is able to make an accurate
identification of structures that are less well visualized
in the static image.

We have examined more than 300 infants and
children with the multiscan method since we began to
evaluate the prototype unit in February 1973. Complete studies of appropriate quality have been obtained in 97% of this patient population. It should be emphasized that the multiscan technique provides satisfactory data even if an infant or youngster cannot maintain an immobile position. Moreover, the time required to complete a multiscan study (approximately 15 minutes) is shorter than with single crystal methods. Lastly, because the visual presentation of cardiac anatomy is more complete, it is far easier to orient and train physicians to recognize alterations from normal anatomy.

In the present study we have demonstrated that cross-sectional echocardiography allows a definition of superior and inferior, anterior and posterior, and right-left orientation of cardiac and extra-cardiac structures. Thus, the method is especially suitable for defining great artery and cardiac chamber orientation and position. We believe the multiscan approach will enjoy its widest applications as an initial test to establish diagnosis, as a pre-catheterization study to more appropriately plan the course of a subsequent hemodynamic investigation, and as a means for serially evaluating patients in whom anatomic findings may change with time. A particularly good example of the latter application was provided by the infant with transposition of the great arteries, referred to previously, who developed left ventricular outflow tract obstruction during the first year of his life. In addition, in an occasional patient confusion exists concerning the precise relationships between the semilunar and A-V valves, even after cardiac catheterization and angiographic studies have been performed. In this regard, especially in the presence of significant intra-cardiac shunting, it may be difficult to define with certainty whether or not mitral-aortic or mitral-pulmonic continuity exists in patients with suspected partial transposition of the great arteries and double outlet right or left ventricle. In these patients cross-sectional studies may offer important supplemental information in clarifying the angiographic findings.

Multiscan echocardiography is technically simple, without known risk, applicable to large numbers of patients, and provides clinically important information to assist in the diagnosis and management of infants and children with cyanotic congenital heart disease.

References


3. King DL: Demonstration of transposition of the great vessels by cardiac ultrasonography. (abstr) American Institute of Ultrasound in Medicine, p 34, 1972


Multiple Crystal Cross-Sectional Echocardiography in the Diagnosis of Cyanotic Congenital Heart Disease
DAVID J. SAHN, RICHARD TERRY, ROBERT O'ROURKE, GEORGE LEOPOLD and WILLIAM F. FRIEDMAN

Circulation. 1974;50:230-238
doi: 10.1161/01.CIR.50.2.230

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1974 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/50/2/230

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/