right ventricle, which may allow the VS, with the LV chamber, to reach a more anterior position, thus attenuating the systolic posterior excursion of the VS. After completion of the stronger systole, the end-systolic volume will be less in the right ventricle and the septum more anterior. The next beat will be weak and associated with a small RV stroke volume and less attenuation of septal movement. The resultant greater excursion during the weaker beat is then the result of factors operating on both sides of the septum.

The initiation or accentuation of pulsus alternans by premature beats was noted by Mackenzie14 and Rihl,15 and subsequently documented both experimentally and clinically by numerous workers. In a series of 71 patients with pulsus alternans (recorded by sphygmograph) reported by White,30 alternation occurred only after premature beats in 55. Ventricular premature beats occurred, with varying frequency, in all our patients; in three of them, postextrasystolic beats enhanced alternans, but mechanical alternans was observed even on occasions when no premature beats occurred over long periods exceeding 50 beats. In one patient (3), alternans was apparent only in the three or four postextrasystolic beats, and not during regular, uninterrupted sinus rhythm.

In conclusion, echocardiography allows the detection of mechanical alternans and thereby provides a helpful additional sign to the clinician, suggesting or confirming the presence of LV failure. Moreover, it provides further insights into the mechanical basis for alternans.

References


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Esophageal Echocardiography

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SUMMARY Esophageal echocardiography has been developed for use in patients with chronic obstructive pulmonary disease and is a safe diagnostic procedure which provides high resolution mirror image echoes of many cardiac structures. Conventional anterior and esophageal echocardiograms were performed in 38 subjects. Esophageal echoes were of diagnostic quality in all 38 subjects; anterior echoes were of diagnostic quality in only 18. Measurements from anterior and esophageal echocardiograms correlated well for aortic valve diameter (r = 0.87), left atrium diameter (r = 0.96), mitral valve EF slope (r = 0.97) and less well for aortic root diameter (r = 0.69). Since its introduction in 1954, cardiac ultrasound has become an important diagnostic tool. One of its major drawbacks, however, has been the inability of external ultrasound to record diagnostic echoes in patients with chronic obstructive pulmonary disease, barrel chests, and obesity. In veterans hospitals, where these patients represent a considerable portion (20%) of echocardiographic subjects, results are frequently poor. In order to obviate this problem, an esophageal echocardiographic transducer was developed and clinically tested.

Method

A 9 mm nonfocussed Aerotech 3.5 MHz transducer was designed and instrumented to permit easy swallowing by...
adults (fig. 1). The transducer is placed in a 1.9 cm × 1.3 cm × 0.6 cm casing with rounded edges for easy esophageal passage. Its blunt end is attached to a calibrated 3 mm coaxial cable which permits sufficient control of rotation at 30–40 cm length, the level of cardiac echoes.

Prior to the study, subjects were fasted. After gargling 20 cc of 2% viscous xylocaine, they swallowed the transducer. Subjects usually fed the transducer to themselves. Most found the procedure innocuous, but three of the 38 subjects did complain of discomfort. No complications were encountered. Cardiac echoes were easily obtained, and the entire procedure required approximately 10 minutes. The transducer's position was identified by the aortic root echo. From this position, advancement and a small degree of left lateral rotation were used to scan the anterior mitral valve leaflet. Esophageal echoes were obtained in sitting and supine positions, and recorded on standard echocardiographic equipment. Figure 2 shows a PA and lateral chest X-ray of the esophageal transducer in place.

Included in this study were normal subjects, patients with various types of heart disease, and patients with obesity, barrel chests and chronic obstructive pulmonary disease. All subjects were first studied with a standard 2.25 MHz or 1.60 MHz external transducer using standard or subxyphoid techniques, and then with the esophageal transducer at the same sitting. Of the 38 subjects included in this study, 20 were selected because of poor quality anterior echoes. Eighteen subjects with good quality anterior echoes were chosen to obtain correlative measurements.* Of the 20 subjects chosen with nondiagnostic anterior echoes, the subxyphoid technique improved yield,* but in our hands was not uniformly successful (only 20%). In four subjects, identification of cardiac structures was confirmed by the indocyanine green dye technique.**

Results

Aortic Root and Left Atrium Studies

Figure 3, Panel A, shows the anterior echo, and Panel B shows the esophageal echo of the aortic root and aortic valve excursion of a subject with mitral valve disease. In the esophageal echo, the aortic valve is seen from its posterior position and is the mirror image of the anterior echo. The aortic root dimension measured by anterior echo was 2.6 cm, compared to 2.0 cm by the esophageal echo. The aortic valve opening measured 1.8 cm by both methods. Figure 4 shows the esophageal aortic valve echo of a patient with chronic obstructive pulmonary disease without clinical evidence of heart disease. The anterior echo was unob-

Figure 1. Photograph of esophageal 3.5 MHz nonfocused transducer.

Figure 2. The PA (left) and lateral (right) chest X-rays of the esophageal transducer in place.

Figure 3. Panel A shows the external echo of the aortic root, aortic valve, and left atrium of a patient with mitral valve disease. Panel B shows the same patient's esophageal echo of the aortic root and aortic valve. Note that the esophageal echo is a mirror image of the external echo and that its resolution is high quality. The chamber anterior to the aortic root is the pulmonary artery, as documented by indocyanine green dye infusion.
Echo was unobtainable. The esophageal echo revealed a normal anterior mitral leaflet, but with reversal of posterior and anterior orientation. Withdrawal and clockwise rotation of the transducer revealed normal transition of the anterior mitral leaflet into the posterior aortic wall. Anterior to the mitral valve, echoes from the anterior left ventricular wall merged into the interventricular septum, which became continuous with the anterior aortic wall. The structure anterior to the aortic root is the right ventricular outflow tract.

Figure 7 compares the anterior echo (Panel A) and the esophageal echo (Panel B) in a patient with mitral stenosis confirmed by cardiac catheterization. The diastolic excursion (D-E) of the anterior leaflet of the mitral valve is similar in anterior echoes and esophageal echoes (1.5 cm and 1.3 cm, respectively). Posterior mitral leaflet echo is seen parallel to the anterior mitral valve leaflet by esophageal echo.

Green Dye Studies

To document various structures visualized with esophageal echocardiography, cardiocyan dye was injected into the various heart chambers, and intracavity pressures and fluoroscopy were used to identify catheter tip position.

Figure 8 shows the esophageal echo of the aortic root and valve. In order to identify the chamber which was situated anteriorly, green dye was injected into the pulmonary artery from a catheter with an end hole just distal to the pulmonary valve (Panel A). Note the lack of echo contrast material. Panel B shows the echo which was obtained during green dye injection following withdrawal of the catheter proximal to the pulmonary valve. This demonstrates the anterior structure to be the right ventricular outflow tract.

Figure 9 shows the esophageal echo of the anterior mitral leaflet. In Panel A, no echo contrast was seen when green dye was injected into the pulmonary artery. In Panel B, green dye was injected into the apex of the right ventricle, and identifies the right ventricular portion of the interventricular septum and the cavity of the right ventricle.
Correlative Data

Figures 10, 11, 12 and 13 show correlative data between the anterior echo and the esophageal echo in the 18 subjects in whom anterior echocardiography was successful. The aortic valve opening measurements correlated well \((r = 0.86)\). In subjects with small aortic valve openings, the esophageal echocardiographic determinations of aortic valve excursion tended to be greater than anterior echocardiography. Comparison of left atrial dimensions by anterior echocardiography and esophageal echocardiography showed a strong correlation \((r = 0.96)\) (fig. 11).

Mitral anterior leaflet EF slope had the strongest correlation between the two methods \((r = 0.97)\) (fig. 12). Mitral posterior leaflet was not obtained in enough subjects. Aortic root diameter (fig. 13) compared by anterior echocardiography and esophageal echocardiography had a weak correlation coefficient of 0.69. In patients with small aortic roots, esophageal echocardiographic dimensions tended to be smaller. In diseases in which the ascending aorta was enlarged, the esophageal echocardiographic measurements were greater. Measurements at various levels above and below the aortic valve confirmed the differences.

**Figure 6.** Esophageal echo scan in a patient with chronic obstructive pulmonary disease. To the left of the illustration the transducer is focused on the anterior mitral leaflet and anterior wall of the left ventricle. Withdrawal and clockwise rotation of the transducer revealed transition of anterior mitral leaflet into posterior aortic wall. Echoes from anterior left ventricular wall merged into interventricular septum which, in turn, became anterior aortic wall. The right ventricular outflow tract lies anterior to the aortic root.

**Figure 7.** Panel A shows the external echo of a patient with documented mitral stenosis. Panel B shows the esophageal echo counterpart with reversed orientation.

**Figure 8.** Panel A shows the aortic root and the aortic valve echo with the typical chamber lying anteriorly. A green dye injection just distal to the pulmonic valve revealed no echoes in the anterior chamber. Panel B shows the same echo, but this time green dye was injected just proximal to the pulmonic valve filling the anterior chamber with echoes and identifying it as the right ventricular outflow tract.
Discussion

Cardiac ultrasound has become useful as a safe, noninvasive method of cardiac evaluation. Its usefulness is limited in patients with a disproportionate distance between the anterior chest wall and cardiac structures, i.e., emphysema, barrel-chested diseases, obesity and the elderly patient. In our hospital population, these patients represent approximately 20% of the population we evaluate by cardiac ultrasound. Neither the subxyphoid technique nor a 1.6 MHz transducer has solved this problem. Development of the esophageal transducer was undertaken to improve the diagnostic accuracy of echocardiography.

The transducer can be swallowed relatively easily and safely. Mild gagging is usually encountered as the transducer passes the cricopharyngeal sphincter. Once beyond this the transducer passes easily. Positioning of the transducer is accomplished by monitoring the echogram during swallowing. Once the aortic valve echoes are localized, advancement of the transducer by 1-2 cm and left lateral rotation (counterclockwise rotation of the cable) produces an echo from the anterior mitral valve leaflet. Further advancement by 0.5 cm to 1 cm and a slight lateral rotation allows scanning of the posterior mitral valve leaflet and posterior left ventricular wall.

With anterior echocardiography, the transducer is generally placed in one position, and cardiac scanning is accomplished by tilting the transducer. In esophageal echocardiography, we scan by advancing and withdrawing the transducer with medial and lateral rotation. This is best accomplished with the patient supine or in the sitting position.

The ultrasound beam is directed anteriorly when first swallowed (fig. 2 right), permitting a direct approach to the left atrium, aortic root, and right ventricular outflow tract, without interposing intrathoracic structures (fig. 8). Green dye studies confirmed the most anterior structure as right ventricular outflow tract. Location, relative positions, and dimensions of this structure can be useful in conal-truncal malposition in congenital heart disease.11 Scanning laterally from the aorta to the anterior mitral valve leaflet, the transducer passes from anterior aortic wall to interventricular septum to a tangential section of the interventricular septum at its junction with the anterior left ventricular free wall. Further lateral rotation yields a clear motion of the endocardium to the anterior left ventricular free wall anterior to the anterior mitral valve leaflet (fig. 6). This approach may make possible cardiac scanning of the anterior.

**Figure 9.** Panel A shows the anterior mitral leaflet with the interventricular septum and right ventricle lying anteriorly. Green dye injected into the main pulmonary artery revealed no echoes in the anterior chamber. Panel B shows the same echo but this time green dye was injected into the apex of the right ventricle identifying the anterior structures on the interventricular septum and right ventricle.

**Figure 10.** Correlative data for aortic valve excursion comparing anterior and esophageal echo. a = anterior echo, E = esophageal echo, open circle = normal patient, closed circle = abnormal patient, dashed line = line of identity, solid line = regression line.

**Figure 11.** Correlative data for left atrium diameter comparing anterior and esophageal echo.
and esophageal echocardiography compared surprisingly well. Because of differences in beam angulation by the two approaches, we expected variation in dimensions. This only appeared significant when comparisons were made of the ascending aorta. With small aortic roots, the aortic size was less by esophageal echocardiography (fig. 13). As aortic size increased, the aortic dimension by esophageal echocardiography was greater. The tendency for a normal-sized ascending aorta to be vertical explains the variation. As the ascending aorta dilates, it elongates horizontally, anteriorly and to the right, thus allowing the anteriorly-directed ultrasound beam to be reflected from a greater transverse diameter.

At the present time we have not been able to obtain left ventricular dimensions as seen by anterior echocardiographic technique. Echoes from the anterior free wall of the LV, posterior wall of the LV and posterior mitral leaflet have not been obtained routinely. One of the current limitations of the technique is the lack of transducer position control. In general, this has not prevented us from obtaining echoes from most cardiac structures. Current efforts are under way to control the transducer position by means of an externally controlled cable, thus enabling determination of posterior and anterior free wall thickness and excursion. In addition, the proximity of the posterior wall of the LV and posterior mitral leaflet with the unfocused transducer beams is thought to be a significant factor. We are currently developing a 5 MHz transducer which should improve yield.

Difficulty may be encountered in the interpretation of esophageal echoes because of their reversed orientation. Electronic reversal of the image was considered, but it was felt that direct image representation was important in orientation to cardiac structural relationships. For this reason, all esophageal echoes in this manuscript have been shown in their original recorded state.

Other approaches to cardiac ultrasound have been used in addition to conventional anterior echocardiography. To date, we believe this is the first report of clinical use of esophageal cardiac ultrasound. Esophageal echocardiography provides high resolution echoes of most cardiac structures. The echo window by esophageal echocardiography is greater than by conventional external echo. This is especially valuable in the patient with nondiagnostic anterior echoes and as an additional tool in evaluating the right ventricular outflow tract and anterior left ventricular free wall.

References

The Natural History of Truncus Arteriosus

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SUMMARY The cases of 23 patients whose condition was
diagnosed as truncus arteriosus, type I or II, and who were seen at the
Mayo Clinic during the decade preceding 1967, that is, before corre-
tive operation became feasible, were reviewed. Ten were infants
(through one year of age), and all ten have died. Eight ranged in age
from more than one year through seven years of age, and all are
living, except one, who died 11 years after diagnosis. Five were
older than seven years, and all had severe pulmonary vascular ob-
structive disease; three have died. Thus, 14 of the 23 have died, and
all but one surviving patient have mild to moderate disability.
The generally grave prognosis for patients with truncus arteriosus
warrants continued use of corrective operation, but suggests
that the greatest benefit can be realized by successful correction
in the infant with congestive heart failure and in early childhood
before the development of severe pulmonary vascular obstructive
disease. Eight patients presented with a history of both con-
gestive heart failure and cyanosis, seven with congestive
heart failure alone, two with cyanosis only, and six with no
symptoms. Eighteen patients had been treated previously
with digitalis. Pertinent data from cardiac catheterization
and angiocardiography are listed in tables 1, 2, and 3.
Moderate to severe pulmonary vascular obstructive disease
(pulmonary resistance [Rp] equal to or greater than 8 U m\(^2\))
was present in ten of the 13 patients in whom complete
hemodynamic data were obtained. Two patients had uni-
lateral absence of a pulmonary artery and four had angi-
ographic evidence of mild to moderate truncal valve
regurgitation. Follow-up information to August 1975 was
obtained for all but one of the survivors, either by re-
examination at the Mayo Clinic or by information from
the referring physician, the parents, or the patient, or from all of
them in answer to a special questionnaire.

Clinical Material

Between October 1957 and September 1967 and before
the advent of a definitive surgical repair of truncus
arteriosus, 23 patients (eight males and 15 females) were
referred to the Mayo Clinic for evaluation of congenital
heart disease (tables 1, 2, and 3). The diagnosis of truncus
arteriosus, type I or II, was confirmed by cardiac
catheterization and angiocardiography, exploratory thorac-
otomy, or autopsy. (We did not encounter type III truncus
arteriosus and prefer to use "pulmonary atresia" to
designate the condition of patients previously classified as
"type IV truncus arteriosus.".) The age at which the patient
was first referred for evaluation varied from 8 days to 16
years. Ten of the 23 patients (43%) were referred for evaluation
of this cardiac defect before the age of two years; in the
remaining 13 the age ranged between two and 16 years (me-
dian 7.4 years). Of the ten infants, only two survived beyond
their second year of life; they died subsequently, 8.5 and 12
years after their initial examination, of congestive heart
failure and acute respiratory infection, respectively. Four of
the older patients died one to 15 years after their initial ex-
adication at this clinic. Thus, a total of 14 patients died:
eight from acute intractable congestive heart failure at a me-
dian age of 19.9 months; one from intractable ventricular
Tachyarrhythmia after cardiac catheterization (8-month-old
infant in congestive heart failure); one from acute
Respiratory infection who was essentially asymptomatic
from the congenital cardiac defect; two of the 3 patients in
whom pulmonary resistance was more than 20 U m\(^2\) died
suddenly at 15 (case 22) and 24 years (case 19) of age.

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