Cross-Sectional Echocardiographic Detection of Aortic Obstruction

2. Coarctation of the Aorta

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SUMMARY Cross-sectional echocardiographic studies of the aortic arch and proximal descending aorta were performed in 18 patients with coarctation of the aorta and 20 normal subjects. In normals the aortic arch and proximal descending aorta appeared as an arcuate, echo-free structure curving across the plane of the scan. There were no localized changes in aortic diameter and the amplitude of aortic systolic pulsation was symmetrically maintained throughout the scan plane.

Visualization of this region was possible in 16 of 18 patients with coarctation. In each of these cases there was a localized area of decrease in aortic diameter in the region of the left subclavian artery which corresponded to the angiographic appearance of the coarctation. In addition prominent systolic pulsation of the aortic arch proximal to the region of obstruction was evident. Cross-sectional echocardiography may offer a useful noninvasive method for direct visualization of aortic coarctation.

THE REPORT BY MECKEL IN 1750 of a young girl with extensive aortic narrowing and congestive heart failure is generally accepted as the original description of coarctation of the aorta.1 Paris, in 1791, first noted the typical localized constriction near the ligamentum arteriosum and gave a detailed description of the anastomoses surrounding the obstruction.3

Anatomically the area of coarctation is characterized by localized deformity of the media of the aortic wall producing a curtain-like infolding which eccentrically narrows the vascular lumen. Externally the aorta exhibits an indentation or localized concavity.5 Although coarctation may occur at any level of the thoracic or abdominal aorta the zone of coarctation is characteristically located just beyond the origin of the left subclavian artery or distal to the insertion of the ligamentum arteriosum.4 The area of coarctation may be well defined and localized (adult type) or there may be a more diffusely narrowed aortic segment beginning distal to the innominate artery and ending in a localized constriction beyond the left subclavian artery (preductal or infantile type).5

M-mode and more recently cross-sectional echocardiography have proved to be valuable noninvasive methods for detecting obstruction at and proximal to the aortic valve.6-20 Recent reports have suggested that echocardiography may also be a useful technique for detecting obstruction distal to the aortic valve in patients with both supra-valvular aortic stenosis and aortic atresia.20-24 Although several authors have demonstrated that recording of the aortic arch from the suprasternal notch is feasible,24-27 to date there have been no reports suggesting that M-mode echocardiography can detect coarctation of the aorta. The reason for this is that classic coarctation lies in an area of the descending aorta where the vessel runs parallel to the path of the ultrasonic beam. This orientation makes it impossible to record an accurate aortic diameter in this region and therefore to appreciate change in vascular size caused by localized narrowing. The purpose of this study was to determine whether the enlarged field of vision and spatial orientation provided by the cross-sectional echocardiographic technique might permit recording of the aortic arch and descending aorta and to determine if any abnormalities in aortic configuration could be visualized in patients with coarctation of the aorta.

Materials and Methods

Cross-sectional echocardiographic studies of the aortic arch and proximal descending aorta were performed in a group of 18 patients with coarctation of the aorta. There were 13 males and 5 females. Ages ranged from 0.04 to 18 years (mean 6.4 years). Diagnosis of coarctation was established in each case by standard cardiac catheterization and angiographic techniques. Peak systolic gradient across the area of coarctation averaged 42 mm Hg (range 9–90 mm Hg).

A control group of 20 normal subjects was also examined. Patients were considered to be normal based on an absence of heart disease, by history or physical examination, and normal M-mode and cross-sectional echocardiograms. There were 12 females and 8 males in this group, ages ranging from 2 to 35 years (mean 13.6 years).

Cross-sectional echocardiographic studies were performed using either a mechanical sector scanner developed at Indiana University in conjunction with the Fortune Fry Research Laboratories or a commercially available mechanical scanner (Smith Kline Instruments, Echo-sector 1). A 2.25 MHz mechanically oscillated transducer focused at 7.5 cm was utilized in each case. Cross-sectional images were recorded on half inch videotape using a Sanyo VTC — 7100 video cassette recorder. The recorded images were available for subsequent analysis in a real-time, slow motion, or single frame format. The images were converted to hard copy using a standard Polaroid photographic system.
Cross-sectional studies of the aortic arch were performed with the patient in the supine position with the neck slightly extended and the head rotated approximately 45° to the left. The transducer was placed directly in the suprasternal notch and the probe directed posteriorly, inferiorly, and leftward to align the plane of the cross-sectional sweep parallel to the long axis of the descending aorta. The typical orientation of the plane of the cross-sectional probe was approximately 45° to both the sagittal and coronal planes of the body. When attempting to identify structures in the descending portion of the aortic arch the left carotid artery was used for orientation. It was possible to readily confirm the identity of the left carotid artery by following this vessel cephalad into the neck. Figure 1 demonstrates the position of cross-sectional probe placement and its relation to the descending aorta. The carotid artery is indicated in this recording.

Results

Normal Subjects

With the transducer placed in the suprasternal notch it was possible to record the aortic arch and proximal descending aorta in each of the 20 normal subjects. The region encompassed by the scan extended from the midportion of the aortic arch to the proximal portion of the descending aorta distal to the origin of the left subclavian artery. The scan area therefore included both the origins of the left carotid and left subclavian arteries.

In normals the aorta in this region appeared as an arcuate echo-free structure originating in the upper left hand portion of the scan. The initial sweep of the vessel from left to right represented the distal half of the aortic arch while the continued arc back across the scan plane from right to left reflected the proximal descending aorta. The diameter of the vessel appeared relatively constant throughout the plane of the scan. In addition to the characteristic appearance of the aortic arch and descending aorta this vessel could be further identified by the characteristic systolic arterial pulsations. In each of the normal subjects systolic pulsation of the entire sweep of the vessel was evident with the amplitude of pulsation appearing symmetrical throughout the sweep of the scan plane. Figure 2 is a recording of a normal aortic arch and proximal descending aorta demonstrating the characteristic appearance of this region. The origin of the left carotid artery is indicated in the diagram to the right.

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Visualization of the aortic arch and descending aorta using the cross-sectional system was possible in 16 of the 18 patients (89%) with coarctation of the aorta. In each of these cases an area of localized decrease in luminal diameter was apparent. The location and configuration of the areas of luminal narrowing or coarctation were similar to the angiographic appearance of the restricting lesions.

Figure 3 is a cross-sectional scan of the aortic arch and proximal descending aorta demonstrating a localized area of decrease in luminal diameter distal to the origin of the left
subclavian artery. The area of decreased diameter is relatively well defined and produces almost complete obliteration of the aortic lumen. Figure 4 is an angiographic recording of the aortic arch from the same subject. The appearance of the area of coarctation on the angiogram is similar to that observed in the cross-sectional echogram. Figure 5 is a cross-sectional recording from a second child with a more diffuse area of luminal narrowing. In this recording the area of apparent decrease in diameter begins proximal to the left carotid artery and extends distally to a point beyond the origin of the left subclavian artery. Figure 6 is an angiogram from the same patient again illustrating a relatively diffuse area of coarctation similar to that seen on the cross-sectional scan.

In addition to the decrease in luminal diameter the pattern of systolic expansion of the aorta proximal and distal to the area of narrowing was different in patients with coarctation. The coarctation group showed very prominent systolic pulsations of the aortic arch proximal to the area of coarctation. Distal to the area of apparent narrowing the aortic pulsation was obviously less vigorous. This is in contrast to the normal group in which the degree of systolic pulsation was less vigorous and was symmetrical throughout the area of the scan.

Discussion

This report describes our initial experience using the cross-sectional echocardiographic technique to record the aortic arch and proximal descending aorta in normal subjects and patients with coarctation of the aorta. Using the suprasternal notch as an echocardiographic window it was possible to visualize these structures in each of 20 normal subjects and 16 of 18 patients with coarctation of the aorta. The potential value of the suprasternal notch as an echocardiographic window has been well documented.35–38 Goldberg originally noted that utilizing this approach it was possible to record M-mode studies of the aortic arch, right pulmonary artery, and left atrium in 130 of 138 patients (94%).36 Allen et al. utilized the suprasternal notch as a portal for recording a cranio-caudal left atrial dimension and suggested that combining this dimension with the standard anteroposterior dimension offered an improved method for determining left atrial volumes in patients with nonspherical left atria.27 More recently these authors29, 30 demonstrated flow of contrast media from the aortic arch into the right pulmonary artery in infants with patent ductus arteriosus confirming the presence of the ductal shunt and permitting the natural history and response to the therapy to be evaluated.
The suprasternal notch has also proved to be a valuable portal for obtaining flow information in the aortic arch and descending aorta using both the pulsed and continuous wave Doppler techniques as well as for Doppler imaging of the aortic arch and efferent vessels. Since the Doppler flow signal is optimally recorded when the flow vector is directly away from the interrogating transducer, the orientation of the aortic arch and proximal descending aorta makes this an ideal area for aortic flow recording. Preliminary Doppler studies have also suggested that alteration in the normal flow pattern in this region may provide diagnostically useful information in patients with coarctation. Thus a wide body of data has accumulated to indicate that echocardiographic recording from the suprasternal notch is a viable and practical method for obtaining structure and flow data for the aortic arch and proximal descending aorta.

From a technical standpoint all previous studies from the suprasternal notch have utilized small, nonmoving transducers which in many cases were manufactured specifically to conform to the anatomic structures in this region. One might anticipate therefore that use of a large mechanically oscillating transducer particularly in infants and children would be technically difficult if not impossible. Surprisingly we found during this study that with proper patient positioning there was relatively little difficulty in obtaining high quality visualization. If patients were allowed to become familiar with the oscillating transducer prior to attempting the suprasternal study, anxiety was alleviated and patient cooperation was good. In addition, because of the close proximity of the aortic arch to the skin surface in the suprasternal notch, studies were generally accomplished quickly and without noticeable patient discomfort. Although infants were clearly more difficult to examine than older children or adults, this did not represent a major technical limitation.

In addition to visualization of this region it was also possible to record local changes in structure and motion patterns in patients with coarctation. In order to record and appreciate areas of luminal narrowing or coarctation it was necessary to visualize both the normal aortic diameter as well as the decrease in diameter produced by the eccentrically placed lesions. Because the orientation of the obstructing lesions in this region is either oblique or perpendicular to path of the ultrasonic beam, changes in luminal diameter must be appreciated on the cross-sectional scans as alterations in the lateral distance between structures. Since the lateral resolution of these systems is inferior to the axial resolution, the definition of the inner margin of the normal vessel and the area of narrowing is less precise than that seen with more appropriately oriented lesions in other areas of the outflow tract. In addition the inner margins of the obstructing lesion lie parallel to the beam of ultrasound and therefore will not themselves be echo producing. One

**Figure 5.** Cross-sectional scan from a patient with a more diffuse area of aortic obstruction beginning in the region of the aortic arch and extending to a point of maximum narrowing distal to the left subclavian artery. Beyond the area of maximal obstruction the aortic diameter returns toward normal.

**Figure 6.** Angiographic recording corresponding to the cross-sectional scan in figure 5. Again a fairly extensive area of decrease in aortic diameter with the region of maximal narrowing or coarctation occurring distal to the origin of the left subclavian artery can be observed (horizontal arrow).
therefore must rely on the echoes from the obstructing shelf to be reflective of the area of obstruction. For these reasons it was not possible to quantitate the absolute change in aortic diameter or severity of obstruction. Despite these difficulties however it was possible to record a clearly evident change in aortic diameter in the region of the coarctation in each of the 16 cases in whom this area was visualized.

Finally during this study we noted very prominent systolic pulsation or expansion of the aortic arch and effenter vessels in the coarctation group. This type of vascular pulsation is a recognized phenomenon which has aided in the clinical diagnosis of coarctation. While prominent systolic expansion of the aorta is not specific for coarctation, it should alert the observer to the possibility that a coarctation may be present. In addition the relatively greater systolic pulsation of the aortic arch proximal to the area of obstruction compared to that seen beyond the obstruction is visually useful in distinguishing patients with coarctation from other groups.

Because the descending aorta in the region distal to the obstruction is almost directly parallel to the path of the ultrasonic beam, precise recording of the inner margins of the aortic walls in this area has not been possible. As a result change in diameter with systolic expansion cannot be determined quantitatively or compared with the percent expansion observed in the aortic arch proximal to the lesion. Despite the lack of quantitation we have found this variation in the pattern of aortic pulsation to be a striking phenomenon and feel that it may be of value to other examiners attempting to detect coarctation in this region.

This study therefore suggests that by using the suprasternal notch as an echocardiographic window it is possible to visualize the aortic arch and descending aorta in a high percentage of both normals and patients with coarctation of the aorta. It further indicates that in patients with coarctation of the aorta an obvious decrease in the diameter of the aortic lumen can be visualized, and that by combining the change in luminal diameter with the characteristic contraction pattern of the aorta proximal and distal to the area of obstruction, a noninvasive appreciation of areas of coarctation may be possible.

It should be noted that in both of these studies patients were selected because of an established diagnosis of aortic obstruction. Although the cross-sectional studies were examined independently and without knowledge of the precise location or extent of the obstructing lesions, it is clear that further prospective studies are required to define the sensitivity and specificity of these techniques as well as the potential causes for false-positive and false-negative diagnoses. These studies demonstrate, however, that when appropriately recorded the cross-sectional echocardiogram can correctly define areas of aortic obstruction and that the appearance of the ultrasonic recordings bears a close relationship to similar angiographic images.

References
Cross-sectional echocardiographic detection of aortic obstruction. 2. Coarctation of the Aorta.
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