Clinical Significance and Origin of Artifacts in Transesophageal Echocardiography of the Thoracic Aorta

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Objectives. The aim of this study was to identify the mechanism and features of artifacts encountered during transesophageal echocardiography of the aorta.

Background. Artifacts are an important potential limitation of transesophageal echocardiography of the aorta.

Methods. The mechanism of the artifacts was examined by in vitro modeling. The frequency and clinical correlates of artifacts were examined by retrospective review of transesophageal echocardiograms in 36 patients with aortic pathologic lesions.

Results. Two classes of artifact were seen: linear artifacts in the ascending aorta, which may mimic intimal flaps, and mirror image artifacts in the transverse and descending thoracic aorta. Linear artifacts in the ascending aorta, seen in 44% of patients, were shown in vitro to be multiple path artifacts caused by reflection of ultrasound within the left atrium. Linear artifacts in the ascending aorta were associated with dilation of the ascending aorta and were more frequent when the aortic diameter exceeded the left atrial diameter (p < 0.001). The mirror image artifacts of the transverse and descending thoracic aorta give the appearance of a double-barrel aorta and were shown in vitro to be caused by the aorta-lung interface, which acts as a total reflector of ultrasound. Mirror image artifacts were seen in 70% of patients. Artifacts were equally frequent with the sagittal and transverse imaging planes when biplane transesophageal echocardiography was used.

Conclusions. Artifacts occur frequently during transesophageal echocardiography of the aorta. An understanding of why they occur and the features that distinguish them from true abnormalities should enhance the diagnostic accuracy of transesophageal echocardiography for aortic disease.

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Transesophageal echocardiography yields detailed images of the anatomy of the thoracic aorta and blood flow velocities. For the diagnosis of aortic dissection the sensitivity and specificity of transesophageal echocardiography are reported to be 97% to 100% (1-3) and 98% to 100% (1-4), respectively. However, the presence of imaging artifacts may be an important limitation of transesophageal echocardiography of the aorta. In a recent report comparing transesophageal echocardiography and nuclear magnetic resonance imaging for the diagnosis of aortic dissection, the specificity of transesophageal echocardiography was only 68% (5). In that series and others, artifacts in the ascending aorta were responsible for the false positive diagnoses and hence reduced the specificity of transesophageal echocardiography. Moreover, in clinical practice a false positive diagnosis of a type I aortic dissection can have catastrophic results.

All ultrasound imaging techniques lead to artifacts, which are primarily caused by reflection of ultrasound back and forth between strong reflective surfaces. These so-called multiple path artifacts (6) introduce apparent boundaries and structures into an image where no structure exists. With the heart and aorta, a multitude of tissue-fluid and tissue-air (lung) interfaces produce an ideal setting for imaging artifacts. Biplane transesophageal echocardiography enhances the visualization of the ascending aorta and may improve the diagnostic accuracy of transesophageal echocardiography (4); however, its effect on imaging artifacts is unknown.

An understanding of why artifacts occur and when they are likely to be seen should allow a true abnormality to be distinguished from artificial structures and should have a major impact on the specificity of transesophageal echocardiography. The purpose of this study was to identify in vitro the physical basis of artifacts encountered during transesophageal echocardiography of the thoracic aorta. In addition, we examined the frequency with which artifacts occur clinically and identified factors associated with the appearance of these artifacts.
AORTA LA

Figure 1. Diagram of the in vitro model for the ascending aorta linear artifact. Two latex balloons, one representing the aorta and one the left atrium (LA), were placed side by side in a water bath. An artifact was consistently present within the aortic balloon when the diameter of the aortic balloon exceeded the diameter of the left atrial balloon (top). The artifact was projected outside the aorta when the left atrial balloon was larger than the aortic balloon (bottom). By altering the diameter of the balloons it was shown that the distance from the aorta-left atrium interface to the artifact (arrow A) equaled the diameter of the left atrial balloon (arrow B). This finding demonstrates that the linear artifact is due to reflection of ultrasound within the atrium.

Methods

In Vitro Experiments

Two sets of in vitro experiments were performed, one to simulate the ascending aorta and one to simulate the transverse and descending aorta. To perform the in vitro experiments we used an ATL Ultramark 9 echocardiographic machine fitted with a 5-MHz transesophageal transducer.

Ascending aorta artifact. Two water-filled rubber balloons were placed side by side in a water bath, one representing the ascending aorta and the other the left atrium (Fig. 1). Ultrasound images of the two balloons were recorded with the 5-MHz transducer placed against the left atrial balloon. The balloon sizes were varied and the resultant images recorded on 0.5-in. (1.27 cm) VHS videotape. Distance measurements were made by using the electronic calipers on the ultrasound machine.

Descending and transverse aorta artifacts. The experiments were conducted by using a glutaraldehyde-fixed porcine aorta. The ultrasound transducer was placed in a large water bath along with the aorta, which was suspended in the water bath by threads. Two sets of experiments were performed.

Figure 2. Diagram of the in vitro model for the mirror image artifact of the descending aorta. A porcine aorta was suspended in a water bath and imaged with a transesophageal (TEE) probe. The air-water interface was used to represent the lung. With the aorta adjacent to the surface of the water (top) a mirror image of the aorta (dotted line) was present. When the air-water interface was absent (bottom) the mirror image was not present. The mirror image is dependent on the presence of the air-water interface.

For the first set of experiments the aorta was viewed in cross section and the images were recorded on 0.5-in. VHS video tape. The surface of the water was used to simulate the tissue-air interface between the aorta and lung. The aorta was placed immediately below the surface of the water and imaged from below (Fig. 2). The resultant images were recorded and then repeated without the air-water interface present.

For the second set of experiments the aorta was imaged longitudinally with the 5-MHz transesophageal transducer. To simulate the flow of blood within the aorta, the aorta was incorporated into a simple steady flow loop at 74 ml/s. Pulsatile flow was not used because the interaction between the flow and the image artifacts should be independent of pulsatile flow. The air-water interface at the surface of the water bath was again used to simulate the air-tissue interface between the aorta and lung. The aorta was therefore placed horizontally in the water bath close to the water surface. The transducer was placed adjacent to the aorta opposite to the surface of the water bath. Two-dimensional ultrasound images of the aorta were recorded on video tape with and without Doppler color flow mapping.

Statistical methods. For in vivo observations, numeric values are reported as mean value ± SD. Statistical analysis of factors associated with the appearance of artifacts was performed by using the chi-square test with the Yates correction. The designated level of significance was p < 0.05.
**In Vivo Observations**

The echocardiograms and charts of patients undergoing transesophageal echocardiography between August 1989 and March 1991 for investigation of actual or suspected aortic lesions were retrospectively reviewed. The echocardiograms were reviewed with particular reference to the presence of pitfalls and acoustic artifacts. Transesophageal echocardiographic results were compared with definitive diagnoses made with other imaging modalities or at autopsy or surgery. For identification of artifacts, we used the definitions and terminology of Kremkau and Taylor (6) in their review of artifacts in ultrasound and the results of our in vitro experiments. We defined a linear artifact of the ascending aorta as the appearance of a structure within the ascending aorta that was proved not to be present by another technique. An artifact involving the descending and transverse aorta (mirror image artifact), was defined as duplication of the aortic image or part of the aortic image when no such structure existed. A pitfall was defined as visualization of a true structure that was interpreted erroneously. The protocol was in compliance with the requirements of our Human Investigation Committee.

Categoric variables were compared using 2 x 2 contingency tables. The Fisher exact test was used to calculate probabilities (p < 0.05 was considered significant).

**Results**

**In Vitro Experiments**

**Ascending aorta linear artifact.** Figure 3A shows an image of the two water-filled latex balloons. The balloon at the top of the image adjacent to the transducer represents the left atrium ("left atrial balloon"). The second balloon is fully visible on the image and represents the aorta ("aortic balloon"). An object was consistently seen within the aortic balloon when the diameter of that balloon exceeded the diameter of the left atrial balloon. Because the balloons contained only water, the object that appeared inside the aortic balloon must be an artifact. By varying the size of the left atrial balloon, the distance between the transducer and the interface between the two balloons was shortened. The distance between the balloon interface and the artifact remained equal to the diameter of the left atrial balloon interface (Fig. 3A). These results indicate that the artifact is created by reflections back and forth within the left atrial balloon. The reflecting surfaces involved are the interface between the two balloons and the interface between the left atrial balloon and transducer face. The artifact is a reflected image of the wall of the left atrial balloon closest to the transducer face.

**Descending and transverse aorta mirror image artifact.** Figure 4 shows a cross section of the porcine aorta obtained with the transesophageal probe. The true image of the aorta is on the top with an artificial mirror image below. The white line across the center is the surface of the water. It can clearly be seen that the artifactual image is of similar strength to the true image. When the air-water interface was not present, the lower artifactual image disappeared, demonstrating that the artifact was due to the presence of this interface (Fig. 2). Figure 5A shows the longitudinal section of the porcine aorta. Again in this case the upper surface of the water-filled tank is acting as the lung and producing a mirror image artifact. As in Figure 4, the true image of the aorta is on the top with the artifactual image below. For comparison, Figure 5B shows an image of the descending aorta obtained in vivo during a routine transesophageal
examination. The true aorta is at the very top with an artifactual mirror image aorta below.

When the porcine aorta was incorporated into the steady flow loop, Doppler color flow imaging revealed apparent flow in the artifactual aorta. The color flow signal was as strong in the artifactual image as in the true aorta. The in vitro images appeared the same as the in vivo image shown in Figure 6.

**Clinical Observations**

Between August 1989 and March 1991, 36 patients (24 male and 12 female, age range 17 to 77 years) underwent transesophageal echocardiography for investigation of aortic abnormality (Table 1). Only those patients with confirmation of the transesophageal images were included in this study. Confirmation was obtained by surgery in 21 patients, autopsy in 2, computed axial tomography in 7, nuclear magnetic resonant imaging in 4 and angiography in 2. The transesophageal echocardiograms were biplane in 23 patients and single plane in 13. The frequency with which acoustic artifacts were encountered is listed in Table 2.

**Ascending aorta.** Linear artifacts were detected within the ascending aorta in 44% of patients. When biplane transesophageal echocardiography was used, the artifact was visible in the sagittal plane in 33% of cases. These linear artifacts in the ascending aorta have indistinct borders, do not display rapid oscillatory movement, may extend through the aortic wall (Fig. 3B) and do not produce clear interruption of the pattern of blood flow in the ascending aorta. The artifact was commonly encountered at the level of the left atrium. In those patients with the artifact, the aorta was more likely to be dilated and its diameter more commonly exceeded the diameter of the left atrium (p < 0.001, Table 3).

**Table 1. Abnormalities Present in 36 Patients Undergoing Transesophageal Echocardiography**

<table>
<thead>
<tr>
<th>Abnormality</th>
<th>Patients (no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic dissection</td>
<td></td>
</tr>
<tr>
<td>Type A</td>
<td>13</td>
</tr>
<tr>
<td>Type B</td>
<td>5</td>
</tr>
<tr>
<td>Aortic aneurysm</td>
<td>8</td>
</tr>
<tr>
<td>Aortic aneurysm</td>
<td>8</td>
</tr>
<tr>
<td>Aortic aneurysm</td>
<td>2</td>
</tr>
<tr>
<td>Aortic transection</td>
<td>2</td>
</tr>
<tr>
<td>Takayasu’s arteritis</td>
<td>1</td>
</tr>
</tbody>
</table>

In one patient a linear artifact on single-plane transesophageal echocardiography was believed to represent an intimal flap of an aortic dissection when the study was originally
Figure 6. In vivo transesophageal echocardiographic image of the descending thoracic aorta obtained in the sagittal imaging plane. The aorta (Ao) is at the very top of the image with a mirror image (MI) of the aorta below. Doppler color flow imaging reveals flow in both the true and the artificial aorta.

performed (Fig. 3B). In light of the in vitro experiments described previously, this is clearly an artifact.

Transverse aorta and descending aorta. Mirror image artifacts of the transverse and descending aorta were present in >80% of patients (Table 2). The artifact was equally frequent in the transverse and sagittal imaging planes. The artifacts appear as reduplication of the aortic lumen (Fig. 5B, 6 and 7). The mirror image was distorted where the wall of the aorta presented a curved surface to the transducer. This distortion occurs with the transverse plane in the descending aorta (Fig. 7) and the sagittal plane in the transverse aortic arch. In patients with left pleural effusions, the mirror image was commonly absent (p = 0.003, Table 4). In one patient with Takayasu's arteritis the mirror image artifact (Fig. 7) led to diagnostic uncertainty and at the time of the examination was believed to possibly represent a chronic dissection or double-barrel aorta.

**Discussion**

In experienced hands, transesophageal echocardiography has achieved a high degree of diagnostic accuracy for the definition and classification of abnormalities of the thoracic aorta (1-5). Even in the best hands, diagnostic errors can occur and artifacts represent an important source of such errors (1,5). In our series, artifacts were noted in a high proportion of patients and in most cases were easily distinguished from true abnormalities. However, in inexperienced hands even a seemingly obvious artifact may be misleading. It is mandatory for those undertaking transesophageal echocardiography to be familiar with the origin and appearance of artifacts they will encounter.

**Linear artifacts of the ascending aorta.** Artifacts involving the ascending aorta represent an important clinical problem, because in cases of suspected aortic dissection, the presence or absence of involvement of the ascending aorta will often determine whether surgery is undertaken. Erbel et al. (1) reported a sensitivity of 99% and a specificity of 98% for transesophageal echocardiographic diagnosis of aortic dissection. In that series of 164 patients, the two false positive diagnoses were made as a result of "reverberations" within the ascending aorta. In a recent reported series of 53 patients (5), the sensitivity of transesophageal echocardiography was very high; however, the specificity was only 68% for the diagnosis of aortic dissection because of artifacts in the ascending aorta that mimicked intimal flaps. In our series of

**Table 3. Characteristics of Patients With Linear Artifacts of the Ascending Aorta**

<table>
<thead>
<tr>
<th>Artifact Present</th>
<th>Artifact Absent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic diameter (cm)</td>
<td>5.0 ± 1.6</td>
</tr>
<tr>
<td>Left atrial diameter (cm)</td>
<td>2.8 ± 0.8</td>
</tr>
<tr>
<td>Patients whose aortic diameter exceeded left atrial diameter</td>
<td>14 of 15 (93%)</td>
</tr>
</tbody>
</table>

*p < 0.001 comparing patients with presence or absence of artifact. Values are expressed as mean ± SD or number (%) of patients.

Figure 7. In vivo transesophageal echocardiographic image of the upper descending thoracic aorta obtained in the transverse imaging plane. The true aorta (Ao) is at the top of the image and a mirror image (MI) of the aorta is below. The mirror image is distorted because the aorta-lung interface is curved. Doppler color flow imaging revealed turbulent flow in the aorta of this patient with Takayasu's arteritis. A mirror image of the turbulent flow was resolved in diagnostic confusion.
Table 4. Relation Between Descending Thoracic Aorta Mirror Image Artifacts and Pleural Effusions

<table>
<thead>
<tr>
<th>Pleural Effusion Present</th>
<th>Pleural Effusion Absent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror image present</td>
<td>3</td>
</tr>
<tr>
<td>Mirror image absent</td>
<td>6</td>
</tr>
</tbody>
</table>

\( p = 0.003 \) (significance of image artifacts in the setting of pleural effusion).

36 patients. linear artifacts in the ascending aorta were recognized in 44% of patients; however, in only 1 case were they so prominent as to produce diagnostic uncertainty.

Multiple path artifacts are well recognized in abdominal ultrasound (6–8) and are due to reflection between two surfaces. In our experimental model the linear artifact was easily reproduced and was shown to be a multiple path artifact resulting from reflection of ultrasound within the chamber adjacent to the transducer representing the left atrium "left atrial chamber" (Fig. 1). The position of the artifact was dependent on the diameter of this chamber. With knowledge of this dependence, the position of the artifact could be accurately predicted (Fig. 3A). In addition, the artifact was seen only within the "atrial chamber" when the diameter of the left atrial chamber was less than that of the aortic chamber. Linear artifacts of the ascending aorta are generally easily distinguished from intimal flaps by 1) the fuzzy and indistinct borders of the artifact; 2) the lack of rapid oscillatory movements generally associated with intimal flaps; 3) the extension of the artifact through the aortic wall; and 4) the fact that the distance between the anterior wall of the left atrium and transducer face equals the distance from the artifact to the anterior wall of the left atrium.

Color flow imaging may be misleading because color will not be displayed over two-dimensional artifacts that the machine assumes to be real objects (Fig. 3B). When there is a discontinuity in the artifact, the color Doppler study may appear to show an entry site of a dissection. However, artifacts will produce no apparent interruption of the pattern of flow in the ascending aorta, and entry site of dissections are generally associated with flow convergence and turbulent jets.

The use of biplane transesophageal echocardiography provides more complete visualization of the ascending aorta. In a series of 22 patients (2) in whom biplane transesophageal echocardiography was compared with nuclear magnetic resonance imaging, the sensitivity and specificity of transesophageal echocardiography were 100% for the detection of aortic dissection and the entry site was detected in all cases. The use of biplane transesophageal echocardiography does not automatically circumvent the problem of artifacts. In our series, linear artifacts in the ascending aorta were visible in the sagittal plane in 35% of cases. This finding is to be expected because the same reflective interfaces are encountered in both the transverse and sagittal planes. The availability of the second plane may enhance the ability to separate artifacts and true abnormality; however, our data do not specifically address this question.

Mirror image artifact of the arch and descending thoracic aorta. The mechanism and features of mirror image artifacts have been well documented in abdominal ultrasonography, in both in vivo and in vitro models (6–8). The mirror image is dependent on reflection between two surfaces, one of which is usually an air-tissue interface. In abdominal ultrasonography the mirrorlike properties of the diaphragm-lung interface are well recognized (7). The air-filled lungs act as a total reflector of ultrasound (7,8). The same property for the aorta-lung interface has not been described.

In our series, the mirror image artifact was encountered in the transverse aortic arch and descending thoracic aorta in >80% of patients. In only one case did this produce a misdiagnosis. The artifact was equally frequent in both the transverse and sagittal imaging planes.

In transesophageal echocardiography of the transverse and descending thoracic aorta, the mirror images depend on the presence of the aorta-lung interface, as our study demonstrated both in vitro and in vivo. In vivo, the artifact was lost where pleural fluid was interposed between the lung and the aorta and also disappeared below the lower border of the lung. In our experimental model the mirror image was seen only when the air-water interface was adjacent to the aorta. The aorta-lung interface is almost an ideal acoustic mirror because 1) the aorta-lung interface is smooth; 2) when the descending aorta is examined in the sagittal plane, the aorta-lung interface is flat; 3) there is little attenuation of the ultrasound by the blood-filled aorta; and 4) the reflecting surface is only a few cm from the transducer, exposing it to higher energy levels of ultrasound to be reflected. This condition was seen in vitro where the mirror image was equal in strength to the original aortic image, making it impossible to differentiate between the true and the false aorta on the basis of image quality. The size and shape of the mirror image can be distorted if the shape of the reflective surface is not flat. This situation occurs in vivo because the lung is wrapped around the aorta; thus, the reflecting surface is concave in the transverse imaging plane for the descending aorta and also concave in the sagittal plane for the transverse aorta. A distorted reflection of the aorta thus results (Fig. 7). When the descending aorta is examined in the sagittal imaging plane there is no distortion of the reflection because the aorta-lung interface appears flat to the ultrasound beam (Fig. 5 and 6).

The mirror image artifact is generally easy to distinguish from a true anatomic structure (Fig. 5B and 6). The mirror image occurs at a predictable distance, related to the width of the aorta, and the double-lumen appearance of the aorta disappears when the lung is not adjacent to the aorta. Recognition of the mirror image is made difficult by the curvature of the aorta, which produces distorted reflections. Recognition of the reflection is also difficult when the aortic anatomy is complex and distorted, as in our patient with...
Figure 8. In vivo transesophageal echocardiographic image of the descending thoracic aorta (Ao) at the level of the diaphragm. This patient has a left pleural effusion (PE) and ascites (A). An artifact (arrow) projecting into the aorta is caused by reflection of ultrasound between the aorta and diaphragm. This was readily appreciated in real time because the artifact moved up and down in unison with the diaphragm as the patient breathed.

Takayasu’s arteritis (Fig. 7). In these situations, the physician may become lost, as though in a hall of mirrors.

Limitations of this study. Our in vitro models and the mechanisms that we have presented for the imaging artifacts are very simple. In our models we have limited the number of reflective surfaces and avoided curved reflective surfaces. In vivo, multiple curved and angulated surfaces are frequently encountered. We have encountered more complex multiple path artifacts in clinical practice. Figure 8 shows a multiple path artifact that might be confused with an atherosclerotic flap. This artifact occurred in a patient with a pleural effusion and ascites because of reflection of ultrasound between the aortic wall and diaphragm, a fact that was readily appreciated during the study because the artifact moved up and down in concert with the diaphragm’s movement.

Pitfalls. Anatomic structures that lead to errors in interpretation are referred to as pitfalls. Pitfalls reported during imaging of the aorta include pleural effusions (Fig. 8), collapsed lung tissue (9), hiatal hernias (19), the hemiazygos vein and spinal cord (10). To avoid such pitfalls one needs a clear understanding of the anatomic relation of normal structures to the aorta and the appearance of pathologic structures seen outside the aorta. In this series, we encountered no diagnostic errors related to pitfalls.

Summary. Artifacts are commonly encountered during imaging of the thoracic aorta with transesophageal echocardiography because of the presence of smooth, highly reflective tissue-fluid and tissue-air interfaces. Linear artifacts in the ascending aorta are due to ultrasound reflection within the aorta and dissection. However, intimal flaps and linear artifacts each have distinctive features. Linear artifacts in the ascending aorta have indistinct borders, do not display rapid oscillatory motion, may extend through the wall of the aorta, do not interrupt the pattern of flow in the aorta and occur very commonly when the ascending aorta diameter exceeds the left atrial diameter; in general, the distance of the artifact from the transducer equals twice the diameter of the left atrium. Mirror image artifacts are seen in the transverse aortic arch and descending aorta where the aorta is adjacent to the lung. The mirror image artifacts give the appearance of a double-lumen aorta and color flow will be seen in the artificial aorta.

A clear understanding of the types and origins of acoustic artifacts is mandatory for those undertaking transesophageal echocardiography and should improve the specificity of the technique for the diagnosis of aortic pathology.

References