Intravascular Ultrasound Imaging in Acute Aortic Dissection

ANDREW R. WEINTRAUB, MD, FACC, RAIMUND ERBEL, MD, FACC,* GÜNTER GÖRGE, MD,* STEVEN L. SCHWARTZ, MD, FACC, JUNBO GE, MD,* THOMAS GERBER, MD,* JÜRGEN MEYER, MD,* TSUI-LIEH HSU, MD, ROBERT BOJAR, MD, FACC, SABINO ILICETO, MD, FACC,† L. CARELLA, MD,† PAOLO RIZZON, MD,† ISIDRE VILACOSTA, MD,‡ JAVIER GOICOLEA, MD,‡ JOSE ZAMORANO, MD,‡ FERNANDO ALFONSO, MD,‡ NATESA G. PANDIAN, MD, FACC

Boston, Massachusetts; Mainz, Germany; Bari, Italy; and Madrid, Spain

Objectives. This study was performed to determine the potential of intravascular ultrasound in the detection and delineation of aortic dissection.

Background. Intravascular ultrasound is a new technique capable of displaying real-time cross-sectional images of arterial vasculature. Its clinical use has been explored mostly in coronary and peripheral arterial circulation.

Methods. Intravascular ultrasound imaging of the aorta was performed using a 20-MHz ultrasound catheter in 28 patients with suspected aortic dissection. All patients underwent contrast angiography; 7 had computed tomography and 22 had transesophageal echocardiography.

Results. Imaging of the aorta from the root level to its bifurcation was performed in all patients in an average of 10 min. No complications occurred. Dissection was present in 23 patients and absent in 5. In the patients without dissection, intravascular ultrasound revealed normal aortic anatomy. In all 23 patients with dissection, intravascular ultrasound demonstrated the intimal flap and true and false lumens. The longitudinal and circumferential extent of aortic dissection, contents of the false lumen, involvement of branch vessels and the presence of intramural hematoma in the aortic wall could also be identified. In cases where aortography could not define the distal extent of the dissection, intravascular ultrasound did.

Conclusions. Our experience in this series of patients with aortic dissection indicates that intravascular ultrasound could be valuable in the identification and categorization of aortic dissection and in the description of associated pathologic changes that may be clinically important. It can be performed rapidly and safely and could serve as an alternative or adjunct diagnostic procedure in patients with aortic dissection.

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Methods

Twenty-eight patients with suspected aortic dissection were evaluated by intravascular ultrasound imaging. In 23 of these patients (12 men, 11 women; 28 to 79 years old), clinical history and physical examination were compatible with or strongly suggestive of acute aortic dissection. All 23 had contrast aortography; 22 patients underwent transesophageal echocardiography as well; 7 had computed tomography. Nine patients underwent surgery. Intravascular ultrasound imaging was performed after either aortography, transesophageal echocardiography or computed tomography. Intravascular ultrasound imaging was performed in five other patients who had vague chest, shoulder and back pain symptoms but with normal coronary arteriography; however, the probability of aortic dissection, although small, needed to be excluded in these patients. Intravascular ultrasound imaging was performed as the first diagnostic procedure in this group, followed by aortography. Informed written consent was obtained from all patients before the procedure, which was performed in accordance with the approval of the individual human investigation committees.

Intravascular ultrasound imaging was performed with a commercially available instrument (2,12). This device includes a 6F or 4.8F, 95- or 100-cm long disposable catheter enclosing a mechanically rotating driveshaft with a 20-MHz ultrasound crystal at its tip (Sonicath, Boston Scientific Corporation). The catheters were interfaced with an imaging console adapted for 20-MHz operation and 360° scans (Diasonics). The ultrasound core is rotated by a motor at 900 rpm (15 frames/s), delivering a real-time, circumferential ultrasound image. The catheter has a proximal tract at the distal end of the catheter and a distal tract at the catheter tip that accept a 0.025-in. (0.635 cm) guide wire. The ultrasound catheter was introduced by way of an 8F femoral artery sheath and was advanced over the guide wire under fluoroscopic guidance. Images were acquired at various levels of the proximal aorta, including aortic root, aortic arch, descending thoracic aorta and abdominal aorta. Adjustments of catheter position, ultrasound gain, depth gain compensation and gray scale were made to obtain optimal images (28). All studies were recorded on a videotape for subsequent analysis.

Data analysis. Each diagnostic test (intravascular ultrasound, transesophageal echocardiography, aortic angiography, and computed tomography) was interpreted in an unblinded fashion. For each imaging modality, the extent of dissection was defined using the De Bakey classification system (29).

Diagnostic criteria for imaging techniques. Contrast angiography. Aortic dissection was defined by visualization of a double lumen or intimal flap (25,30). The location of the intimal tear was identified by a discrete site in which contrast was seen to pass from one lumen to the other. Aortic regurgitation was diagnosed when contrast entered the left ventricle.

Computed tomography. Visualization of two distinct lumena separated by an intimal flap or displacement of intimalcalcium was required for the diagnosis of aortic dissection (23,24). The presence of a low attenuation crescentic region along the aortic wall was identified as aortic wall hematoma (31).

Transesophageal echocardiography. The presence of an intimal flap separating a true and false lumen was evidence for the diagnosis of dissection (22). Aortic wall hematoma was defined as a focal, crescent-shaped thickening of the aortic wall, usually containing a hypoechoic area (32). Entry sites were identified when there was disruption in the continuity of the flap or a discrete flow jet toward the false lumen that emanated from a well defined location of the intimal flap (33). Thrombus was defined as a collection of soft, granular echoes within the false lumen (34). Aortic insufficiency was diagnosed when color flow or spectral Doppler detected diastolic turbulent flow into left ventricular outflow tract from the aorta.

Intravascular ultrasound. Aortic dissection was deemed present when an intimal flap, a curvilinear structure with rapid, often chaotic motion, could be identified separating the aorta into a true and false lumen (19–21). As with transesophageal echocardiography, thrombus was diagnosed by the appearance of soft granular echo signals and aortic wall hematoma when a focal area of thickening occurred that appeared atypical for plaque. Sites of perforation in the intimal flap were identified as gaps in the flap with asynchronous motion on either side of the tear. This was distinguished from "dropout," a localized area with loss of signals.

Statistical analysis. Sensitivity and specificity were calculated by comparing the results obtained with intravascular ultrasound for the diagnosis of dissection, branch involvement with angiography and thrombus or hematoma in the false lumen with transesophageal echocardiography. The 95% confidence intervals were calculated using the normal approximation to binomial distribution.

Results

Intravascular ultrasound examination in the 28 patients demonstrated aortic dissection in 23 patients and a normal aorta in 5. In the 23 patients with clinically suspected acute aortic dissection, aortography and another technique, transesophageal echocardiography or computed tomography, demonstrated evidence of aortic dissection. Comparative results of each imaging modality are summarized in Table 1. Eleven patients had De Bakey type I dissection, five had type II, and seven had type III. In each of these patients, intravascular ultrasound imaging clearly identified the presence and extent of aortic dissection. In the five patients who had intravascular ultrasound as the primary procedure to exclude aortic dissection, no evidence of dissection was noted on the ultrasound images (Fig. 1). Aortography in these patients was normal. The sensitivity and specificity for
intravascular ultrasound in the diagnosis of aortic dissection was 100%. The average time required for intravascular ultrasound imaging was 10 min. There were no complications related to the imaging procedure.

Intravascular ultrasound findings for aortic dissection. Whereas normal aorta was seen as a circular cross-sectional image with an intact aortic wall and a clear lumen, aortic dissection was displayed on the two-dimensional intravascular ultrasound images as disruption of the aortic wall, with the intimal layer projecting into the aortic lumen, separating true and false channels (Fig. 1 to 3). The appearance was similar to that seen on transesophageal echocardiograms, except that the imaging field was circular and the ultrasound catheter and the guide wire were seen within the true lumen (Fig. 4). The intimal flap could be seen either aligned with one area of the wall if the dissection was small or coursing across the lumen if the dissection was extensive. In all cases, the curvature, shape and mobility of the intimal flap were seen. Locations where the intima was separated from the wall and those where it remained attached could be well defined, allowing us to assess the circumferential extent of dissection. The pulsatile motion of the intimal flap during systole was helpful in the differentiation of the true and false lumina. In some patients, it was difficult to obtain complete cross-sectional images of the vessel within a single frame of the image display at the aortic arch level and at locations where the aorta was aneurysmally large, because of the difficulty in maintaining the ultrasound catheter in a central and coaxial orientation and because of the limited depth of field associated with 20-MHz catheters. Despite this problem, we were able to verify whether the arch was involved in the dissection because it was possible to interrogate most parts of the arch and other enlarged regions of the aorta in some orientation, even when perfect cross-sectional orientation was not available (Fig. 5 and 6). Precise delineation of the entry site tears in the intima was possible in six patients (Fig. 6). However, recognition of the beginning of the dissection in other patients was not difficult because the separated intima could be visualized in all, if not the entry tear. In all 23 patients, the proximal site of intimal separation and the distal end of the dissection could be recognized, and the categorization of the type of aortic dissection by intravascular ultrasound, whether type I, II or III, corresponded to the observations by aortography, transesophageal echocardiography or computed tomography.

The true and false lumina and their relative cross-sectional areas at different levels could be discerned by intravascular ultrasound in all patients. Figures 1 to 4 show examples displaying various degrees of lumen compromise. Only a moderate reduction in lumen area is noted in the example shown in Figure 1; Figure 4 demonstrates a true lumen that accounts for only a very small portion of the overall aortic cross-sectional area. Real-time imaging also revealed the spiral nature of the intimal tear often encountered in aortic dissection. In some cases, the fast-flowing blood in the true lumen and relatively slow-flowing blood in the false lumen exhibited granular moving signals that were recognizable by intravascular ultrasound.

Changes in the aortic wall due to hemorrhage into the media were also visualized by intravascular ultrasound. In

Figure 1. Intravascular ultrasound images from a patient with a normal descending thoracic aorta (left) and a patient with DeBakey type III aortic dissection (right). The ultrasound catheter (c) is noted within the true lumen (TL). The aortic wall appears intact in the normal subject (open arrows); the intimal layer (small solid arrow) appears separated from the wall in the patient with dissection. Both the true and false lumina (L) are seen as relatively sonolucent areas.
Figure 2. Intravascular ultrasound images from a patient with aortic dissection. The schematic (middle) depicts the levels at which the images were acquired. The intimal flap and the true (TL) and false (FL) lumina are well visualized. The intimal flap is seen to extend into the right iliac artery (arrow). c = ultrasound catheter.

Figure 3. Aortogram (top left) and fluoroscopic (top right) and intravascular ultrasound (bottom) images from a patient with type I aortic dissection. Aortogram shows an extensive dissection flap (arrow) coursing through the aortic tree. The fluoroscopic image demonstrates the ultrasound catheter tip (arrow) in the descending thoracic aorta. A guide wire is noted extending to the level of the aortic arch, and a pulmonary artery catheter is also seen. In the intravascular ultrasound image, the ultrasound catheter is seen as a small ring (C). The true lumen (TL) of the aorta is separated from the false lumen (FL) by the dissection flap. The surrounding adventitia of the aorta is seen as the outermost hyperechoic structure.
one patient who was found at surgery to have a large dissection flap and extravasation of the blood through the adventitia in the thoracic aorta, transesophageal echocardiography revealed extensive dissection of the aortic wall, with multiple dissection tracts within the wall of the aorta. These findings were also noted by intravascular ultrasound (Fig. 7). The intramural hematoma was displayed on intravascular ultrasound as increased wall thickness and an irregular appearance of the wall architecture. In this patient, the dissection and mural abnormalities extended to the level of the lower abdominal aorta by catheter ultrasound.

In all patients, the distal end of aortic dissection could be defined by intravascular ultrasound. In three patients, aortic dissection was seen to extend distally to the iliofemoral vessels (Fig. 2). The involvement, or lack thereof, of other aortic branches could be recognized in 14 patients. Overall, the sensitivity for intravascular ultrasound to detect involvement of a branch vessel in the dissection was 89% (95% confidence interval [CI] 78% to 100%); specificity was 100.

Figure 8 is an intravascular ultrasound image from a patient with type III aortic dissection. In this patient, intravascular ultrasound revealed that the celiac artery appeared to originate from the true lumen. At the renal artery level intravascular ultrasound demonstrated that the left renal artery communicated with the false lumen, whereas the right renal branch was in continuity with the true lumen. This was consistent with the findings on aortography.

Comparison of intravascular ultrasound with transesophageal echocardiography, computed tomography and aortography. Twenty-one patients had transesophageal echocardiography and intravascular ultrasound imaging (Table 1). The abnormalities noted in terms of the presence and circumferential extent of aortic dissection and the lumen characteristics were similar with both techniques (Fig. 4 and 7). In six patients who had a dissection that involved the abdominal aorta, transesophageal echocardiography was unable to demonstrate the distal extent; conversely, intravascular ultrasound clearly defined the distal-most extent of aortic dissection. In three of these patients, the iliac or renal artery

Figure 5. Intravascular ultrasound image at the level of the aortic arch from a patient with type I dissection. The dissection involves the arch (left) with dissection flap (arrows) separating the false (FL) from the true lumen. The innominate artery (right) is seen originating (arrows) from the aorta (AO). The dissection flap is shown to involve this branch (arrowheads) with a small false lumen (asterisk).

Figure 6. Intravascular ultrasound image at the level of the aortic arch from a patient with a type I dissection. An entry tear (arrow) in the intima is seen. In real time, the edges of the intima adjacent to the tear demonstrated chaotic motion. Abbreviations as in Figure 1.
Figure 7. Transesophageal echocardiographic (top) and intravascular ultrasound (bottom) images of the descending thoracic aorta from a patient with a type III dissection. The aortic wall in this region is thickened by the presence of hematoma within the aortic wall, which was confirmed at operation. The extent of intimal disruption and the intramural hematoma (asterisk) have a similar appearance in both images. Abbreviations as in Figure 1.

was affected. Understandably, this was not demonstrable by transesophageal echocardiography, although intravascular ultrasound identified the branch involvement. Dissection of the ascending aorta could be identified by both techniques; however, transesophageal echocardiography depicted the dissection in this part of the aorta more clearly than intravascular ultrasound. Multiple communications between the true and false lumens often identifiable by transesophageal color Doppler were not demonstrated by intravascular ultrasound. Transesophageal echocardiography also denoted the lack of involvement of coronary arteries in nine patients with type I or II dissection, but intravascular ultrasound could not provide that information. Eight patients had thrombus or aortic wall hematoma evident on the transesophageal echocardiogram; these findings were noted on intravascular ultrasound in only four patients. Compared with transesophageal echocardiography, the sensitivity of intravascular ultrasound in the detection of thrombus or hematoma in the false lumen was 50% (95% CI 15% to 85%); specificity was 100%.

Eight patients underwent computed tomographic and intravascular ultrasound imaging. Computed tomography did not provide any important additional information; in fact, in four patients computed tomography was unable to define the distal end of the dissection or other dissection-related abnormalities as clearly as intravascular ultrasound. Although the aortic wall was seen by both techniques, intravascular ultrasound provided higher resolution images of the aortic wall and intimal flap. However, the aorta was seen in its entire cross section irrespective of its size by computed tomography at all levels, whereas the 20-MHz ultrasound catheters we used could not display the whole aorta at the level of the aorta or at regions of aneurysmal dilation.

All patients had contrast aortography, and in all both intravascular ultrasound and contrast aortography detected dissection. Aortic regurgitation could be seen by aortography in three patients but not by intravascular ultrasound. Extension of intimal tear into the innominate artery was evident in one patient by aortography but not by intravascular ultrasound. In another patient, continuation of the dissection into the right iliac artery was not shown by aortography but was observed by intravascular ultrasound. The distal portion of dissection in the abdominal aorta was better defined by intravascular ultrasound than aortography in three other patients.

Figure 8. Intravascular ultrasound images of the abdominal aorta in a patient with type III dissection obtained at the level of the celiac artery (left) and at the level of the renal arteries (right). In the image on the left, the celiac artery appears to arise from the true lumen of the aorta (arrow). The ultrasound catheter ring signal is seen in the true lumen. The dissection flap is seen separating the true from the false lumen. In the image at the level of the renal arteries, the right renal artery is in communication with the true lumen (solid arrow); the left renal artery is supplied by the false lumen (open arrow). These relations were better identified in the real-time images.
Discussion
Our experience with the use of intravascular ultrasound imaging in this series of patients with aortic dissection indicates that this method of imaging could be valuable in the identification and categorization of aortic dissection. In addition, catheter-based ultrasound appears to have the capability to describe many of the pathologic changes related to aortic dissection, such as degree of lumen compromise, presence or absence of clot in the false lumen and involvement of aortic branches. Our observations also point to the relative ease and safety of this procedure.

Detection and categorization of aortic dissection. Intravascular ultrasound identified aortic dissection equally as well as transesophageal echocardiography, computed tomography and aortography. Similarly, it was able to exclude dissection as reliably as contrast aortography. Delineation of the type of aortic dissection was also possible because the aorta could be imaged in its entirety from the level of the aortic root; thus the proximal and distal points of intimal tear could be identified. Findings in this study indicate that intravascular ultrasound is probably superior to other techniques in defining the distal extent of aortic involvement. The problem of a catheter entering the false lumen is well known in the performance of aortography. Initial ultrasound examination could determine whether the catheter is in the true or false lumen before contrast angiography, thereby preventing inadvertent injection into the false lumen and extension of the dissection. The ability to visualize the vessel lumen from the moment of introducing the ultrasound catheter into the femoral artery makes it possible to first recognize the distal end of the dissection process by the images of the intimal flap. As one enters the region of aortic dissection, the curvature and pulsatile dynamics of the intimal flap aid in ensuring that the ultrasound catheter is indeed in the true lumen. During intravascular ultrasound examination, as the catheter is advanced in a retrograde manner into the more proximal portions of the aorta with continuous imaging, the torn aortic wall and other related abnormalities become evident. If the cross-sectional size of the aorta exceeds the imaging field, periodic reorientation of the ultrasound catheter allows examination of all quadrants of the aortic wall at any level. It is not surprising, therefore, that detection of aortic dissection and determination of its extent were possible by intravascular ultrasound in every case in this series. Although our experience in this study suggests that intravascular ultrasound is highly reliable in recognizing the presence or absence of aortic dissection, inferences as to diagnostic sensitivity and specificity are not possible because the series is small, the patients included were not consecutive, and the study was not performed prospectively with blinded interpretation.

Depiction of abnormalities associated with aortic dissection. In addition to determining the type of aortic dissection, intravascular ultrasound appears to be capable of providing information on other aspects of this disorder that may be essential for optimal patient management (27). The degree of lumen compromise, presence or absence of thrombus in the false lumen, intramural hematoma, periarteric extravascular hematoma and branch involvement can be ascertained. Similar to transesophageal echocardiography, intravascular ultrasound depicts the intimal flap and the true and false channels, and the circumferential extent of the tear is easily defined. Unlike transesophageal echocardiography, intravascular ultrasound clearly displays the dissection process in the abdominal aorta and the involvement of the abdominal aortic branches. Knowledge about branch involvement—dissection into the renal arteries, for example—may influence therapeutic strategies in type III dissection, for which a conservative medical management is usually employed. Detection of the involvement of aortic arch branches and coronary arteries was difficult with 20-MHz devices but may be easier with lower frequency ultrasound catheters. Thrombosis of the false lumen may influence management decisions in some patients (35), and the intraluminal clot is displayed by intravascular ultrasound. Intramural dissections and extravascular clots may indicate rupture or impending rupture (32); our observations suggest that this complication may be identified by intravascular ultrasound. Pericardial effusion, another complication of dissection, was not observed with intravascular ultrasound in this study. We have previously shown, however, that effusions can be readily detected by placing the transducer within the heart itself (36,37). If information concerning ventricular function or effusion is desired, it can be potentially provided by continued advancement of the catheter across the aortic valve into the left ventricle. At the current state of intravascular ultrasound technology, detection of aortic insufficiency is not possible by this method. However, this may not be a major drawback because most patients with aortic dissection often undergo conventional transesophageal echocardiography, which readily displays aortic regurgitation even when it is unable to depict the dissection.

Comparison of intravascular ultrasound with other imaging modalities. It cannot be stated that intravascular ultrasound is superior to other diagnostic techniques used in detecting aortic dissection, such as transesophageal echocardiography, contrast aortography, computed tomography and magnetic resonance imaging. On the basis of our experience, however, we suggest that this imaging modality appears to have the potential to provide similar, if not identical, information. Transesophageal echocardiography is probably the most useful method to detect and define aortic dissection even though it cannot depict the abdominal aorta (22,38,39). Although intravascular ultrasound may not provide all the data supplied by transesophageal echocardiography, the amount of information available by intravascular ultrasound (proximal site, type, extent, lumen contents, mural abnormalities) may be adequate for patient management in many cases. Computed tomography and magnetic resonance imaging are useful in aortic dissection, but it takes considerable time to mobilize the team and acquire data. Contrast aortog-
raphy defines the branch involvement and aortic regurgitation well, but this technique has well known limitations: It requires radio-opaque contrast medium; it often does not clearly define the intimal flap and extent of dissection (particularly in the distal end); the wall of the aorta is not visualized; and false negative diagnoses do occur, necessitating another test (26). Intravascular ultrasound can be performed without the need for radiopaque dye and can be considered a form of aortography without contrast medium, or it may serve as an adjunct to aortography, providing additional information. If intravascular ultrasound is used in conjunction with aortography, imaging first with this technique could ensure the placement of the aortography catheter in the true rather than the false lumen, as occasionally happens. The major advantage of intravascular ultrasound is its capability to visualize the abdominal aorta and its side branches.

Limitations and future directions. The major limitations of our study were the small number of patients involved and the fact that ultrasound studies were not subjected to blinded interpretation. Although the sensitivity and specificity of intravascular ultrasound were both 100%, and no complications were observed, these data should be interpreted cautiously in light of the small number of patients and the unblinded review. The wide 95% confidence intervals for diagnosis of branch involvement and presence of thrombus or hematoma reflect the small sample size. Some technical limitations to intravascular ultrasound must also be considered. Intravascular ultrasound is an invasive technique; however, in our experience it was safely and easily performed. Experience with larger numbers of patients is required to verify the safety of this technique.

Another major limitation pertains to the high frequency (20 MHz) ultrasound catheters used. Although 20-MHz catheters provide excellent resolution images in small vessels, such as coronary and peripheral arteries, the depth of imaging field is limited. This precludes complete visualization of the cross-sectional anatomy when the aorta is dilated. In half of the patients studied, the overall cross-sectional area of the aorta was too large to visualize in one imaging field. Difficulties in aligning the catheter coaxially within the aorta may also result in only portions of the vessel imaged in one field. These problems occurred most commonly in the region of the ascending aorta and aortic arch; however, this did not affect the ability to diagnose dissection because an intimal flap was visible in all regions. Although this may not affect the ability to detect aortic dissection, the abnormalities associated with dissection, such as side branch involvement (as stated previously), may not be well defined in some patients. This may be overcome by using devices capable of imaging to greater depths. Recently, ultrasound catheters with lower frequency transducers (10, 12.5 and 15 MHz) have been shown to allow an expanded depth of field and to display the great vessels and cardiac structures (37,40). Such proficiency may enhance the diagnostic capability of intravascular ultrasound in aortic dissection. However, because the current generation of intravascular ultrasound transducers do not have Doppler capability, flow dynamics within the aorta and the presence or absence of aortic insufficiency could not be assessed. Facilities for immediate three-dimensional reconstruction of intravascular ultrasound images may increase the potential of this technique in aortic dissection (11,41). Intravascular ultrasound may also be useful in new approaches being explored, such as endoluminal stenting for management of aortic dissection (42). Further investigations using low frequency devices in larger series of patients could define the precise clinical role of intravascular ultrasound in aortic disorders.

Conclusions. Intravascular ultrasound is a potentially useful tool for the diagnosis of aortic dissection and delineation of the extent of dissection as well as branch vessel involvement. Although this technique is invasive, contrast agents are not required, and it can be performed separately, with or without concomitant contrast angiography. Clinical uses for this technique include diagnosis of dissection when transesophageal echocardiography is contraindicated or undesirable, perhaps because of esophageal pathology or recent ingestion of a meal, or in addition to transesophageal echocardiography when further delineation of the dissection into the abdominal aorta is desired. Further studies with larger numbers of patients are required before this promising technique can be adopted for routine clinical use.

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References

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