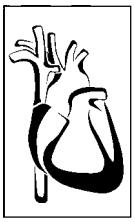

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Limitations of Coronary Angiography Compared With Intravascular Ultrasound: Implications for Coronary Interventions

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The use of intravascular ultrasound catheters to produce images of lumen and plaque cross-sectional areas has had a profound effect on the practice of interventional cardiology. This imaging modality provides, for the first time, a low-power microscopic view of vascular anatomy within a living patient. This article will review some of the advantages of intravascular ultrasound imaging compared with angiography when used for diagnostic or interventional therapeutic procedures.

Coronary angiography is the primary mode of imaging coronary artery disease and guiding interventional procedures. Although coronary angiography was essential for the development of catheter-based coronary interventions, as the complexity of interventional cases increased, several limitations of angiography surfaced. Problems associated with coronary intervention, such as acute closure and restenosis, are related in part to properties of the lesion. Angiographic studies have reported inconsistent predictors of such adverse events.[1,2] One of the main reasons for this inconsistency is the limited power of angiography to delineate the complex anatomy of coronary atherosclerotic lesions. Intravascular ultrasound (IVUS) is a technique that provides two-dimensional, tomographic views of the coronary lumen and wall morphology in vivo, which has several advantages compared with angiography.[3]

This article reviews the limitations of angiography and describes the information that IVUS imaging provides to complement angiography during diagnostic and interventional procedures. The ability of IVUS to evaluate lesion characteristics and dimensions alters therapeutic decisions and permits the operator to optimize each intervention.

Lesion Evaluation

Evaluation of coronary atherosclerotic lesions by angiography has been described by the joint American College of Cardiology/American Heart Association (ACC/AHA) committee.[4] This system delineates lesions by the degree of eccentricity and complexity. However, this analysis is limited by the ability of angiography to visualize only the lumen and not the atherosclerotic plaque itself.

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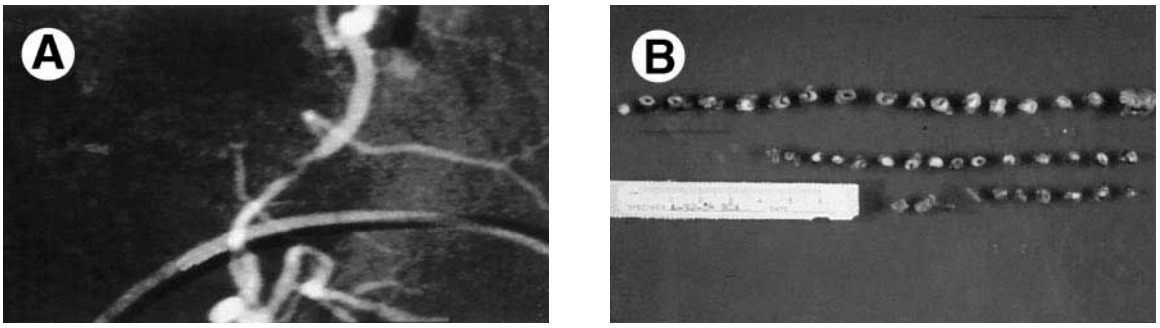

Fig 1. (A) A case example of a right coronary artery disease. (B) Pathologic cross sections of the right coronary artery.

IVUS provides new insights for lesion evaluation because it produces a tomographic view of the artery and it is the only technique that permits visualization of the diseased artery wall in vivo. This capability is especially useful for diagnosing disease when vessels overlap or if there is a short stenosis. In addition, IVUS images are at a higher magnification than angiography, and its internal scale has been shown to be more accurate than angiographic assessment of plaque dimensions. Moreover, the ability of angiography to provide information on tissue characterization is limited. The following discussion will attempt to describe these differences between angiography and IVUS.

Tomographic Imaging

An angiogram shows a longitudinal, two-dimensional view of the lumen of the vessel and does not directly show us the pathology, that is, the atherosclerotic plaque. If the plaque impinges on the lumen, then the indentation is used as a measure of the severity of the atherosclerosis. This method may lead to a false sense of security for several reasons. Because the lumen edges of an angiogram may have a smooth border, we assume that there is not a lot of disease in the vessel.[5] Pathologic studies show that the amount of atherosclerosis is underrepresented by angiography.[6-12] In Fig 1A, the angiogram of a right coronary artery (RCA) shows severe stenosis in the mid portion, but it was felt that the rest of the artery did not have significant disease. Unfortunately, this patient did not survive an intervention of balloon angioplasty for the mid RCA stenosis (this study was performed before stents became available). The corresponding pathologic cross sections (Fig 1B) were taken every 5 mm along the length of the RCA, posterior descending, and posterior lateral branches. The diffuse nature of atherosclerosis is shown in every cross section. Although this phenomenon was counterintuitive to most angiographers, it became more readily accepted throughout the 1980s with the concept of vascular remodeling and compensatory dilatation proposed by Glagov et al.[13] In their pathologic study of 125 left main coronary arteries, it was shown that as the amount of atherosclerosis increased, the outer diameter of the vessel increased but the lumen remained constant until approximately 40% of the cross-sectional area was filled with plaque. At that point, the outer dimension could not enlarge adequately to compensate for the increase in plaque area; the lumen became narrow and only then would it be recognized as diseased on angiography. As shown in Fig 2, the lumens from artery sections 1 through 4 would all appear to be the same on angiography, and all four would be erroneously considered normal. In distinction to angiography, IVUS looks beyond the lumen and reflects information directly about the pathology within the arterial wall. Thus, IVUS can distinguish normal from progressive stages of atherosclerosis in vivo.[14] IVUS studies confirm that arteries frequently expand radially as the

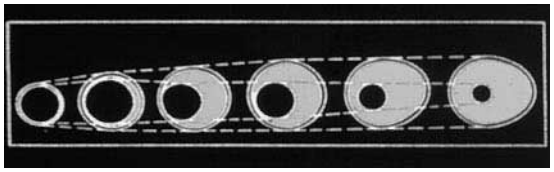

Fig 2. Compensatory enlargement of a coronary artery.

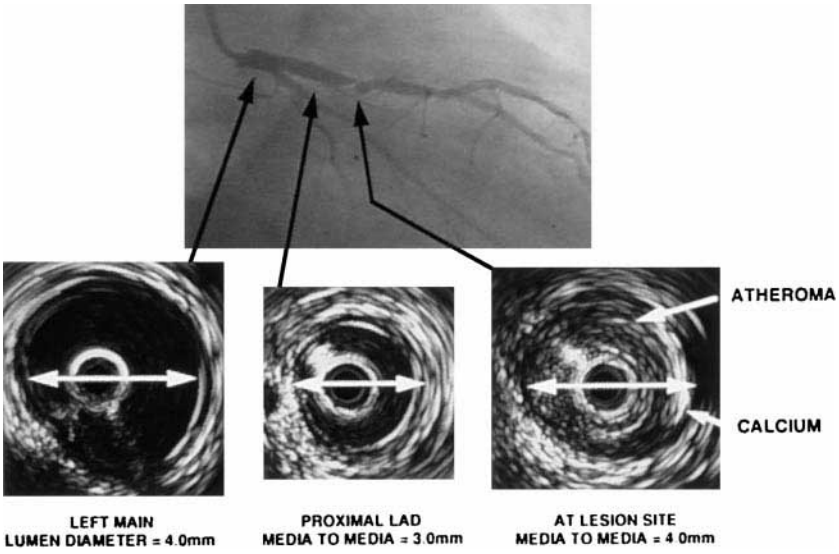

Fig 3. A case example of compensatory enlargement.

plaque enlarges while maintaining the lumen cross-sectional area so that adequate blood flow is provided (Fig 3).

Vessel Overlap or Short Stenoses

Several in vitro and clinical studies have shown that IVUS and angiographic measurements of lumen diameter correlate well when there is minimal disease or if the lumen is circular.[15] However, angiography can be misleading, especially when there is an overlap of vessels or if a short stenosis is present. Figure 4 provides evidence for what has been called a "napkin ring" stenosis.[16] This is a very short stenosis, only 1 to 2 mm in length, such that even in multiple angiographic projections, contrast is in front of or behind the stenosis, which makes the stenosis appear less significant than it is. The angiogram of this symptomatic patient suggests that a mild stenosis is present in the proximal left anterior descending coronary artery (LAD), but on IVUS imaging, the real stenosis is in the mid LAD, where the ultrasound catheter is wedged into the speckled reverberations of plaque. The mid LAD was treated with balloon angioplasty with relief of the patient's symptoms.

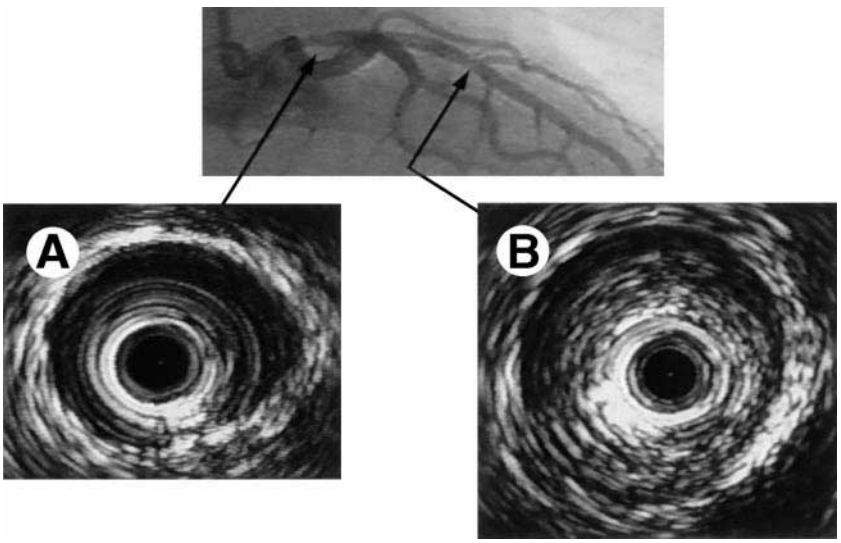

Fig 4. A case example of a napkin ring stenosis.

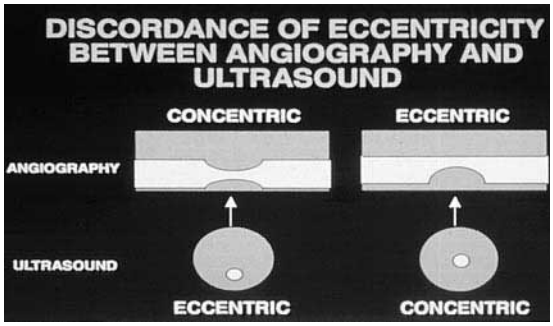

Fig 5. Misdiagnosis of eccentric lesions.

Accurate Measurements—Magnification and Scale

Magnification and scaling errors reveal another major difference between angiography and IVUS for quantitative analysis.[17,18] With angiography, there are significant magnification assumptions when using the guiding catheter as the ruler. A 2.7-mm guide catheter represents only 11 pixels in a 640 × 480 pixel matrix. When measuring an artery edge, one could easily be off by 1 or 2 pixels, which for an artery between 1 and 4 mm is nearly 10% of the ruler. With IVUS imaging, the "ruler" is inherent in the image and is based on the speed of sound in tissue at 37°C. These observations suggest that quantitative coronary angiography has been given too much credence in our literature and design of studies. We should not confuse the reproducibility that computerized measurements provide with accuracy in representing complex luminal topography. It is similar to squeezing a 3–decimal place accuracy from a technique whose scale may be incorrect by several tenths of a millimeter.

Misdiagnosis of Eccentric Lesions

Another area where there is disagreement between ultrasound and angiography is in the description of plaque eccentricity.[14,19-21] As schematically shown in Fig 5, an angiogram that is described as showing a concentric lesion may, in fact, appear to be eccentric on cross-sectional imaging with ultrasound because the plaque itself is not visualized on the angiogram. Conversely, an eccentric plaque by angiography may appear to be concentric on cross-sectional imaging with ultrasound, as shown in the right-hand panel. This discordance between angiography and ultrasound for the description of plaque eccentricity occurs in approximately 20% of lesions. This observation undermines the validity of this angiographic descriptor as a predictor of responses to coronary interventions.

Tissue Characterization

Because angiography describes only the lumen of the vessel, this method cannot identify characteristics of the plaque beyond gross thrombus or calcification. Ultrasound patterns of tissue reflection can be used to characterize more subtle plaque composition.[22-25]

Although calcification can be visualized with fluoroscopy, IVUS provides information about plaque morphology and composition such as fibrous tissue and lipid components or intralumi-

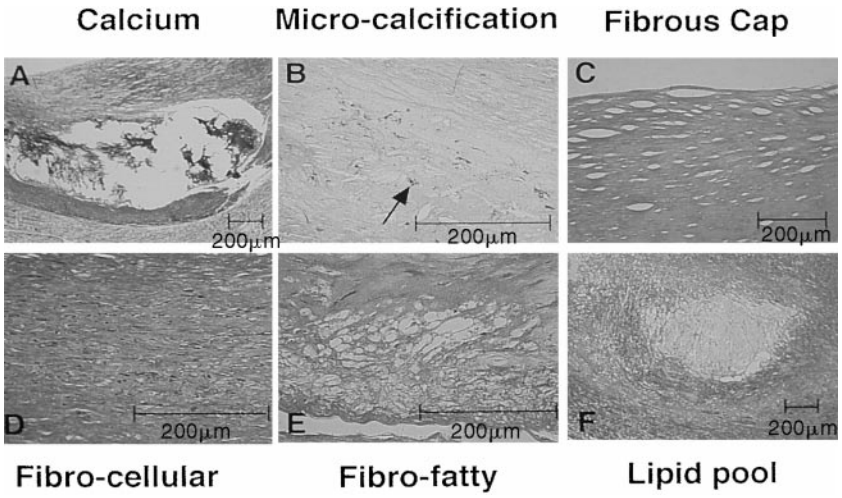

Fig 6. Histologic tissue types.

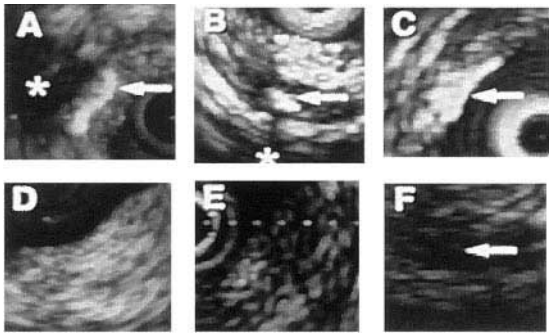

Fig 7. Tissue characterization by intravascular ultrasound imaging.

nal thrombus. As shown in Fig 6, when histologic tissues are segregated into 6 general types, such as calcification, microcalcification, fibroacellular, fibrocellular, fibrofatty, and fatty tissue, the corresponding ultrasound pictures show the following characteristics (Figure 7): (1) calcium has the unique characteristic of being intensely echo reflective at the initial interface with dropout of echoes peripherally, which is termed *shadowing* (Fig 7A); (2) using the same description, microcalcification can be identified as a very small area, 0.1 to 0.2 mm in diameter with intense echo reflections and a small radiating arc of shadowing behind it (Fig 7B); (3) a fibrous acellular capsule (Fig 7C) appears on ultrasound as an intense echo reflection that may be equal or greater than the adventitia echogenicity, but it is distinguished from calcification because there is no shadowing behind it; (the next three categories show a more mixed pattern) (4) mixed cellularity interspersed within fibrous tissue is depicted on ultrasound images as a homogenous black and white speckled pattern with moderate echogenicity (Fig 7D); (5) as fatty elements increase within the plaque, the echogenicity decreases as reflected in the fibrofatty plaque of Fig 7E, which has more black or echolucent areas within the echogenic fibrous tissue; and (6) a large deposition of lipid or necrotic tissue within the body of the plaque is more likely to be represented by a homogenous echolucent zone as shown in Fig 7F.

Angiography may also be misleading in the diagnosis of thrombus formation. This can have significant implications in terms of the type of

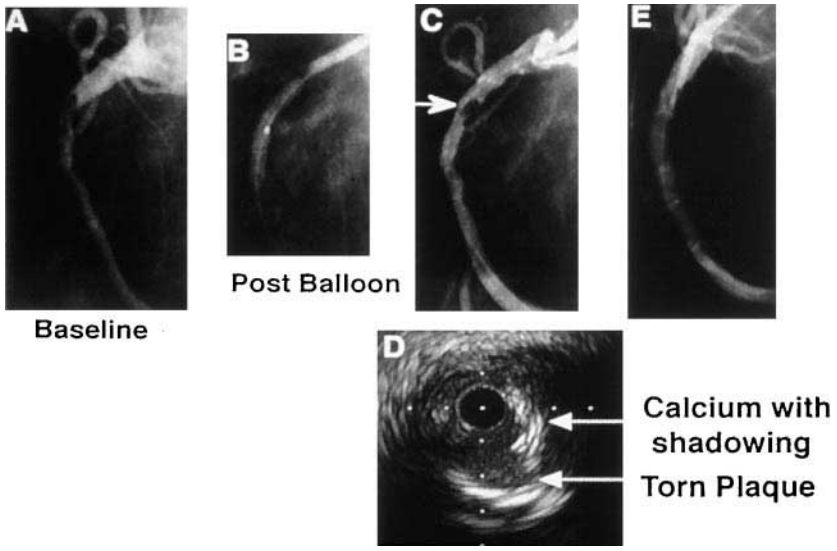

Fig 8. Acute inferior wall myocardial infarction. The baseline angiogram revealed a filling defect in the proximal right coronary artery consistent with thrombus (A). Following several balloon dilatations, flow was improved, but there was still a significant residual filling defect that had the appearance of thrombus (C). Rather than proceeding with thrombolytic therapy, TEC, or Angiojet thrombectomy, an IVUS catheter was passed, with the results shown (D). The IVUS image revealed the presence of intense calcification between the 1- and 7-o'clock positions, with evidence for torn plaque, which has also shifted its position. Based on the IVUS information, an AVE-GFX stent was deployed without the persistent recoil that was seen following balloon dilatation alone (E).

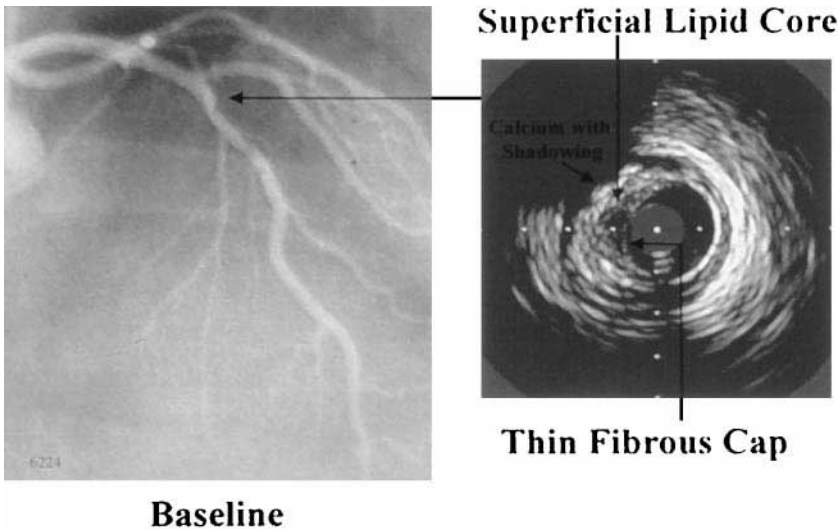

Fig 9. The angiogram reveals a linear stenosis in the proximal LAD before the first septal perforator. Just proximal to the stenosis is an eccentric plaque that appears to have a mixed composition based on tissue characterization. Between the 9- and 12-o'clock positions, there are some intense echo reflections with shadowing peripherally consistent with calcified tissue. In the central portion of the plaque between the 8- and 10-o'clock positions, the plaque is more echolucent with a thin band of echogenic reflection at the lumen surface. This image indicates that under the thin fibrous capsule, there is a central core of lipid laden cells with denser fibrocalcific disease at the base of the plaque.

treatment that is attempted. An example of an apparent thrombus diagnosed by angiography is depicted in Fig 8.

Most investigators report a high sensitivity of identifying calcium as a hyperechogenic area with shadowing.[26-28] Unfortunately, the ability of IVUS to distinguish fibrous from fatty tissue becomes less exact with sensitivity on the order of 50%.[29] It would be beneficial if IVUS images could consistently and accurately identify those plaques with a thin fibrous capsule and a lipid-rich core that are ripe for rupture (Fig 9).[30,31] This type of histologic pattern has been described as a likely precursor to acute plaque rupture and thrombus formation that may precipitate unstable syndromes or acute myocardial infarction.[32,33] Unfortunately at the present time, the sensitivity for identifying these plaques is limited, and we have not used this information to preemptively treat a plaque based solely on its tissue components of a lipid core. It has been reported that analysis of unprocessed radiofrequency (RF) signals may work better for tissue characterization than conventional video IVUS images.[34] Moore et al performed RF analysis in an in vitro setting and showed that parameters of power and spectral slope could discriminate between various tissue types. Clinical studies are needed to test if the RF analysis is more reliable than the image interpretation computer in our brain.

Representation of Calcium Amount and Position

One of the important observations of IVUS is the recognition of a higher incidence of plaque calcifi-

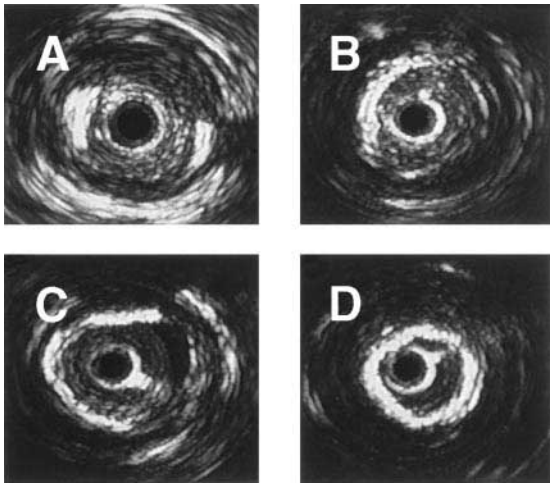

Fig 10. Varieties of calcification.

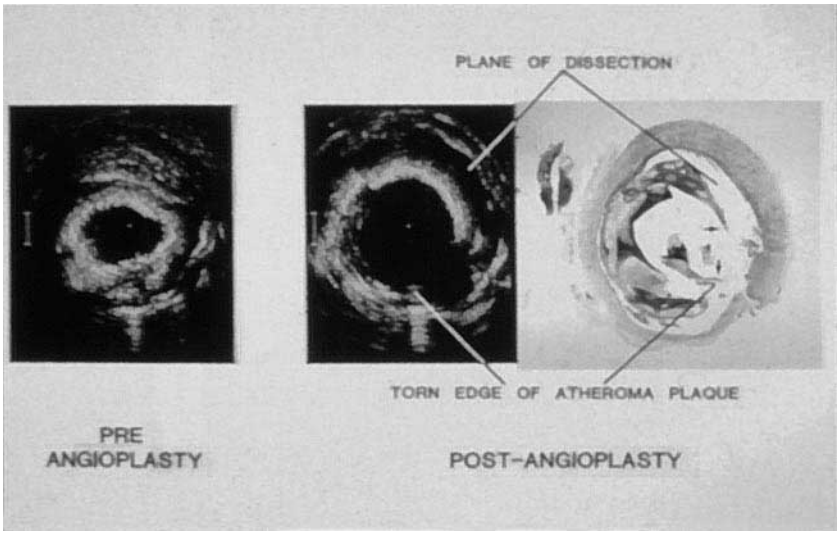

Fig 11. Mechanism of lumen enlargement by balloon angioplasty.

cation than is appreciated by angiography.[35-37] Angiography identifies calcium at the site of a stenosis in only 15% of cases, whereas some degree of calcium is seen by ultrasound in up to 85% of these stenoses. The high sensitivity for depicting calcified areas of plaque has been useful in showing the distribution of calcium throughout the length and circumference of an artery on a micro-anatomic scale.[38,39] As shown in Fig 10, calcified areas frequently occur at the base of the plaque but may subtend a variable circumference. Figure 10 shows calcified plaque at the lumen-plaque interface. These types of plaque are very resistant to balloon dilatation alone and impede stent expansion. When calcification is seen at the lumen-plaque interface, rotational atherectomy is usually necessary. Understanding the composition and biomechanical hardness of the plaque may be very useful when deciding what type of interventional device should be used.

Balloon Angioplasty

Overestimation of Percutaneous Transluminal Coronary Angioplasty (PTCA) Effect

In vitro studies using IVUS before and after balloon dilatation of atherosclerotic segments help to explain the mechanism of action of balloon angioplasty. Histologic studies show that the plaque is frequently torn at its thinnest segment or, if the plaque is calcified, the tear usually occurs at the junction of fibrous tissue and the calcified portion.[40-49] Compared with histologic assessment, IVUS has the benefit of

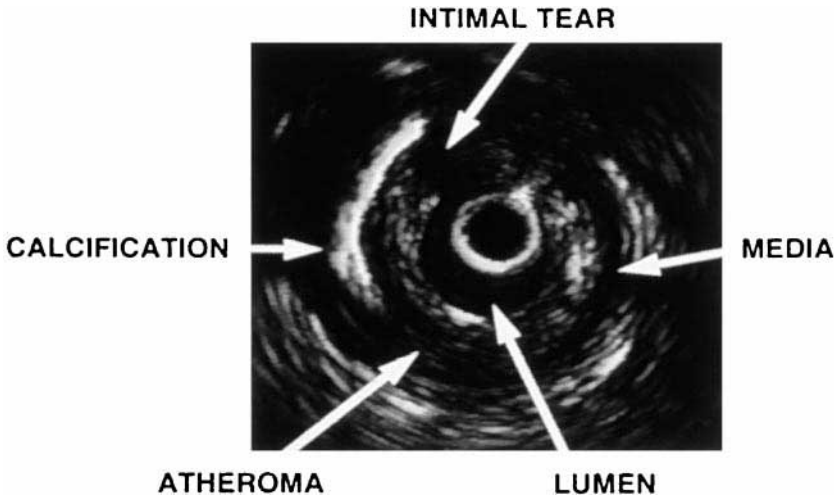

Fig 12. Intravascular ultrasound imaging after successful balloon angioplasty.

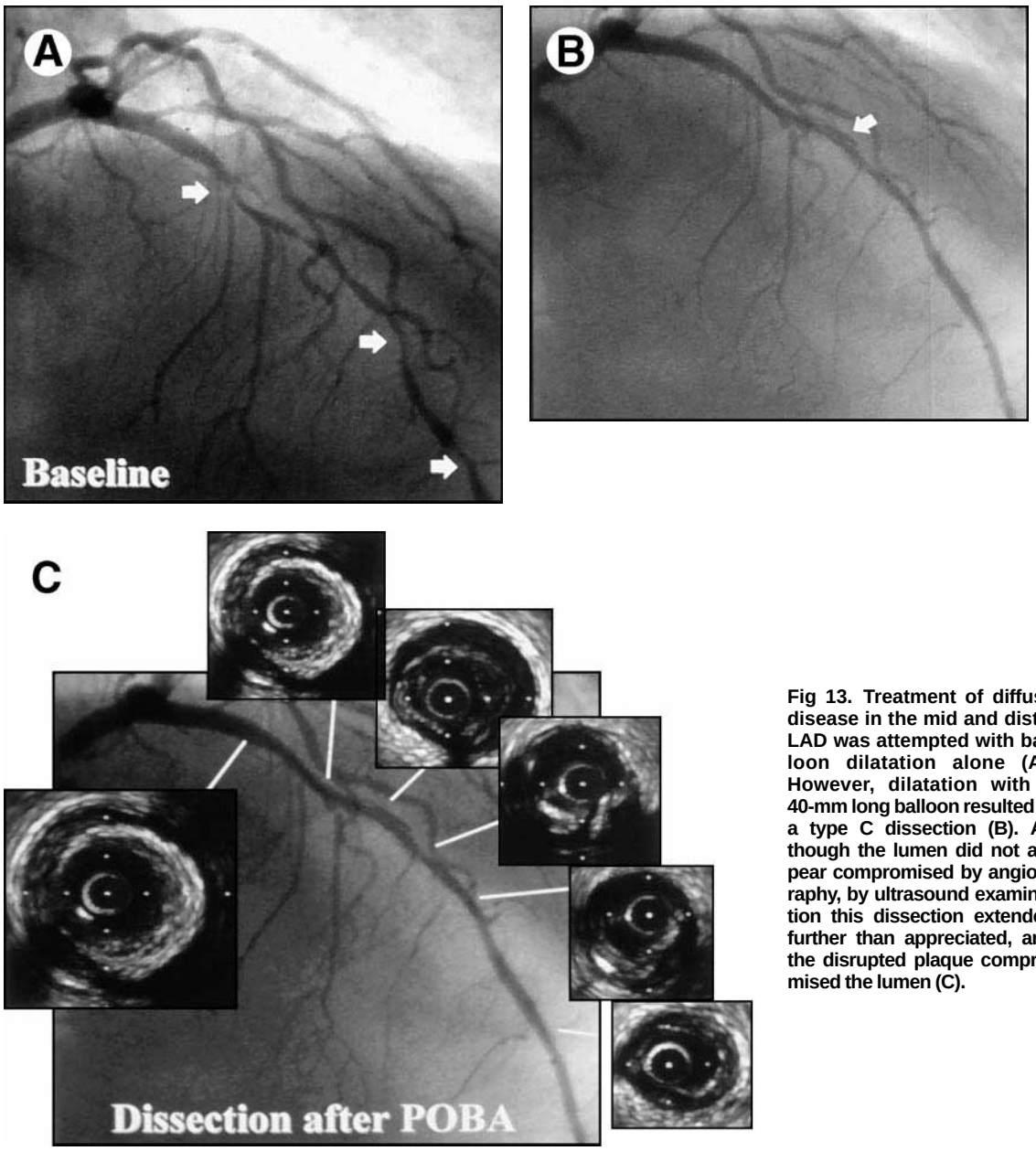

Fig 13. Treatment of diffuse disease in the mid and distal LAD was attempted with balloon dilatation alone (A). However, dilatation with a 40-mm long balloon resulted in a type C dissection (B). Although the lumen did not appear compromised by angiography, by ultrasound examination this dissection extended further than appreciated, and the disrupted plaque compromised the lumen (C).

being able to image the artery before, as well as after, balloon dilatation.[50] As shown in Fig 11, IVUS images before and after balloon dilatation show that the lumen enlarges because of plaque fracture and separation of the torn ends. In addition, a new echolucent zone behind the plaque corresponds to dissection of the artery where the plaque is separated from the media. Occasionally, when larger balloons are used, the entire plaque may be rotated free from the media due to torsional forces that leave an entire ring of dissection around the circumference of the plaque. These dissections do not necessarily result in collapse of the plaque into the artery because it may be supported at its proximal and distal ends to the vessel wall.

When IVUS imaging was initially applied to patients who had balloon angioplasty, some of the observations were quite unexpected.[51,52] As opposed to the angiographic results that suggested that a large lumen had been obtained, the usual

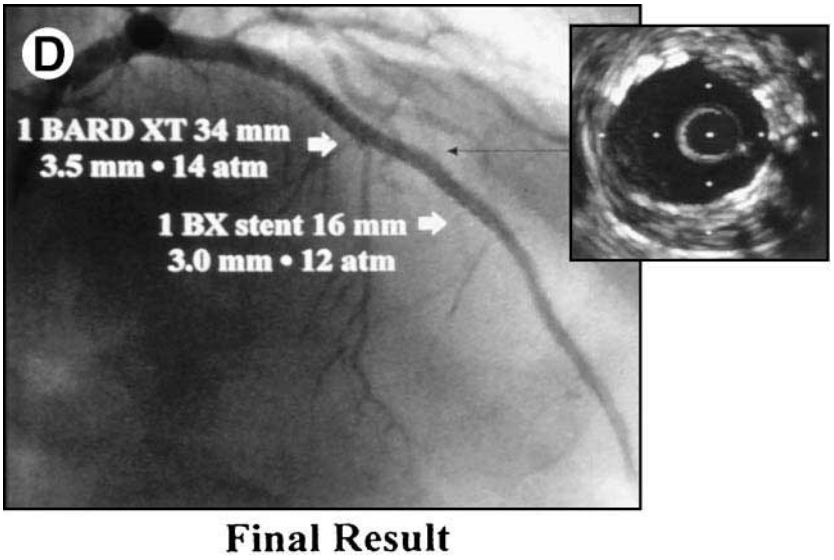

Fig 13. (Cont'd) This dissection was treated with a 34-mm long Bard XT stent and a 16-mm long BX stent (D). Although the risk of restenosis may be over 40% due to the length of these stents, it is imperative that arterial patency is maintained.

finding with IVUS was that only a relatively small tear had occurred in the plaque with separation of the torn ends (Fig 12). One was immediately impressed with the large amount of residual plaque that remained after balloon dilatation.[53] After seeing IVUS images, one could understand how easily restenosis occurs by elastic recoil and mild intimal proliferation; the wonder was how balloon dilatation yielded as high a degree of long-term success as it did.

The second major observation on the mechanism of balloon dilatation was the change in the lumen area from systole to diastole once the plaque had been fractured by the balloon. Although the volume of plaque had not been altered by balloon dilatation, the lumen cross-sectional area was dramatically increased by pulsatile blood flow in diastole. Conceptually, the plaque acts as a scar that immobilizes the wall of the artery. By cutting the plaque, balloon dilatation permits freer mobility of the arterial wall in response to the change in lumen pressure, thus increasing blood flow.[54]

Assessment of Dissections

A dissection after balloon angioplasty was originally thought to be a predictive marker of acute closure; however, abrupt closure occurs in only 5% of PTCAs with angiographic signs of dissection.[55] Inducing dissections has been considered an integral part of lumen enlargement with balloon angioplasty, but not all dissections are equivalent. A dissection represents an adverse event when it compromises the lumen. If a dissection is associated with less than Thrombolysis in Myocardial Infarction (TIMI) 3 flow, it should be treated. However, when dissections are associated with TIMI 3 flow, further evaluation beyond angiographic assessment should be considered, such as IVUS interrogation[56] or coronary flow measurements. IVUS can detect circumferential and longitudinal extension of plaque fracture or dissection after balloon angioplasty.[51,57] In a study comparing quantitative coronary angiography and IVUS,[58] a large discrepancy between these two modalities was reported, particularly when dissections were present after balloon angioplasty. These results indicate that angiography is not an optimal means to evaluate the vessel lumen after trauma from balloon dilatation. A case example of how IVUS helps in the decision to place a stent for the treatment of a coronary dissection is shown in Fig 13.

Other Stenoses Within the Target Vessel

IVUS may be helpful during percutaneous coronary interventions to discover other lesions in the vessel that require treatment to obtain an optimal result. An example of this is shown in Fig 14.

Underestimation of Vessel Size

Many studies have shown that a major determinant of restenosis is the percent diameter stenosis

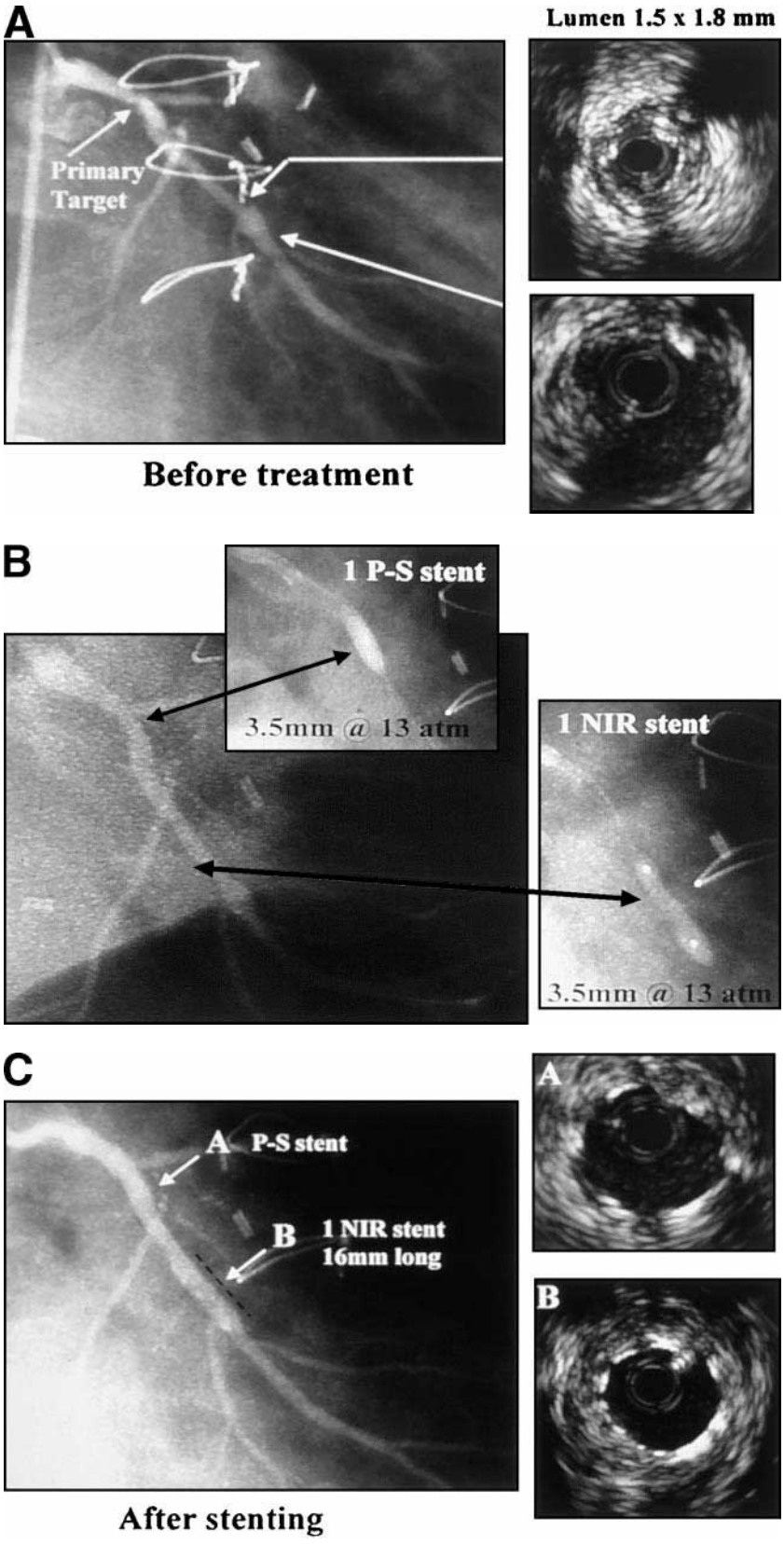

Fig 14. (A) A significant stenosis in the distal left main and proximal circumflex artery, which was the target lesion to be treated. IVUS was performed before the intervention. In addition to recognition of the disease in the proximal artery, IVUS showed a tight stenosis in the mid portion of the obtuse marginal artery that was underestimated by angiography. A 16-mm long NIR stent was placed at 13 atm using a 3.5-mm diameter balloon in the mid portion of the obtuse marginal artery (B). The proximal lesion was then treated with a Palmaz-Schatz stent deployed on a 3.5-mm balloon at 13 atm. The final angiographic result (C) reveals a satisfactory lumen in the proximal and mid portion of the obtuse marginal artery. By IVUS, the lumen measured 3 mm in diameter.

or minimal luminal diameter achieved after intervention.[59-65] Based on these findings, Don Baim introduced the so-called "the bigger, the better" doctrine. Although this rule of thumb may be appropriate for stents and directional atherectomy, indiscriminate use of balloons larger than the angiographic reference segment lumen may result in unacceptably high rates of ischemic complications after PTCA.[66,67] Since its initial description by Andreas Gruntzig in 1978,[68,69] PTCA has been performed by selection of a balloon with a nominal diameter approximating that of the normal-appearing reference segment adjacent to the lesion. A distinction needs to be made between the angiographic definition of artery size and the vessel size observed on IVUS. Whereas angiography uses the proximal reference lumen diameter to denote the artery size, IVUS defines the vessel size as the media-to-media diameter. Because arterial remodeling with compensatory vessel enlargement develops to preserve the lumen,[7,13,70] the vessel size by IVUS may be significantly greater than the lumen size by angiography. The extent of atherosclerosis in both the lesion and reference segments can be accurately measured on-line with IVUS imaging.[71-73] It was hypothesized that IVUS guidance could be used safely to accommodate oversized balloons in selected patients undergoing PTCA. Stone et al[74] showed that despite the presence of atheromatous remodeling, IVUS permits the safe use of balloons traditionally considered oversized, resulting in significantly improved luminal dimensions without increased rates of dissection or ischemic complications (Clinical Outcomes With Ultrasound Trial [CLOUT] Pilot Trial). Because the degree of plaque burden and the true vessel size can be determined only with IVUS, the use of ultrasound is thought to be essential for the accurate selection of properly sized balloons if an aggressive balloon strategy is to be safely performed.[74] Figure 15 shows an example how quantitative coronary angiography (QCA) may be misleading compared with IVUS imaging for assessing the artery size.

Understanding the Mechanisms of Restenosis

Restenosis remains a major limitation to percutaneous coronary revascularization. It occurs in 30% to 50% of transcatheter procedures within the first 6 months.[75-78] Animal models,[79-82] human necropsy studies,[43,83-92] and analyses of retrieved atherectomy specimens[93-99] originally suggested that an exaggeration of the normal reparative processes after angioplasty-induced local vessel trauma leads to uncontrolled smooth muscle cell proliferation and restenosis.[100-102] However, these early studies that showed restenosis was due primarily to intimal hyperplasia may have been misleading. Animal and clinical studies suggest that arterial remodeling with constriction of the adventitia might be a major contributing factor to the development of restenosis.[103-111] Using serial IVUS, Mintz et al observed that two thirds of restenosis was due to adventitial contraction, or "negative remodeling," and only one third of restenosis was explained by intimal proliferation.[112] Kimura et al reported that the time course of arterial remodeling after coronary angioplasty or atherectomy was characterized by early enlargement of the vessel (1 day to 1 month) and late constriction of the vessel (1 to 6 months).[113] They called the early and late vessel changes adaptive and constrictive remodeling, respectively. Recently, this postintervention arterial remodeling process was confirmed by a serial volumetric (three-dimensional) IVUS analysis.[114]

Patients with diabetes appear to respond differently to coronary interventions.[115] Although both diabetics and nondiabetics develop adventitial constriction to produce late lumen loss in nonstented lesions, diabetics show exaggerated tissue proliferation, which may explain their increased rate of restenosis.

Future strategies to reduce restenosis should target prevention of late constrictive remodeling and enhancement of adaptive remodeling as well as suppression of intimal hyperplasia.

Directional Atherectomy

Directional Atherectomy (DCA) was introduced to reduce the restenosis rate compared with balloon angioplasty; however, two initial randomized trials reported no significant benefit with this technique.[60,116]

Overestimation of Cutting Versus Stretching Effect of DCA

IVUS has provided significant insights into the mechanism of action of DCA and helps us to understand why the restenosis rate of early trials, such as the Coronary Angioplasty versus Excisional Atherectomy Trial (CAVEAT) or the Cana-

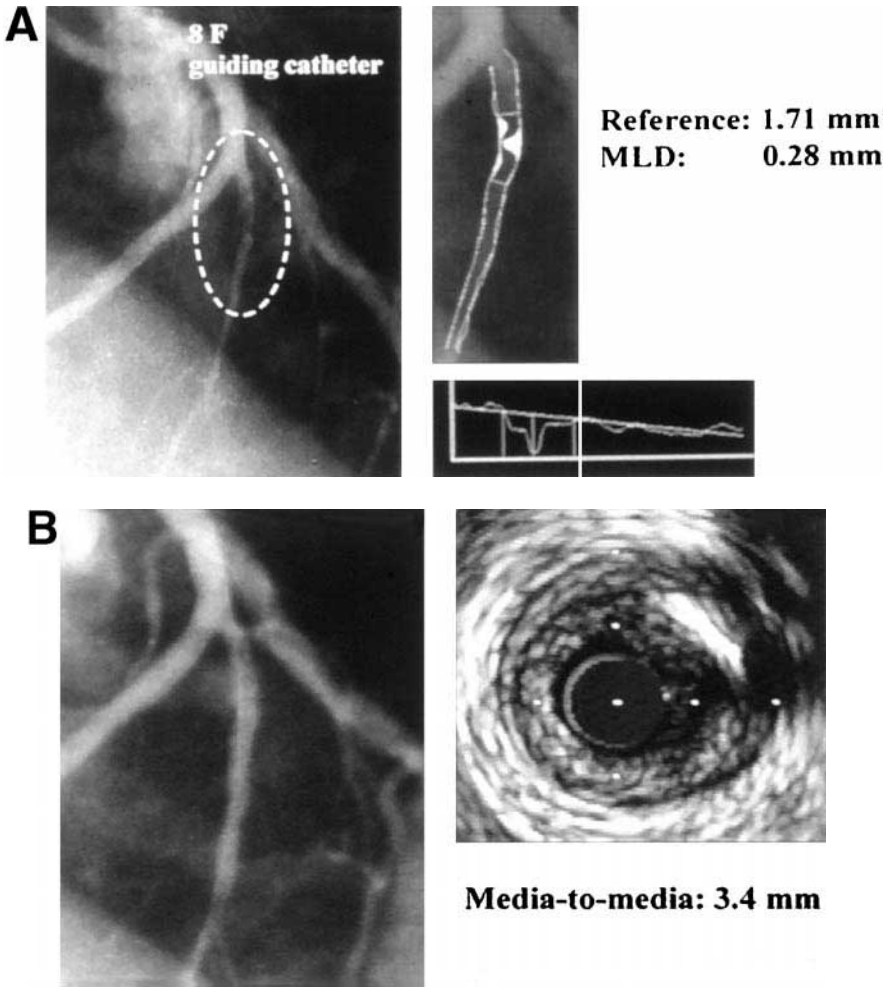

Fig 15. The tight stenosis shown (A) measured 0.3 mm by QCA with a reference diameter measurement of 1.7 mm. Based on this measurement, an aggressive balloon size was chosen at 2.5 mm diameter, which was expanded to 16 atm. The angiogram following the initial angioplasty (left) is shown (B) along with the IVUS image (right). The angiogram shows a successful angioplasty result, and although there is some haziness around the lumen, the boundary shows complete effacement of the stenosis. The corresponding ultrasound image reveals that the lumen size has enlarged to 1.5 mm in diameter; however, the vessel diameter from media to media is much larger than expected at 3.4 mm. The large amount of plaque distributed uniformly throughout the length of the vessel forces QCA to underestimate the true size of this large diagonal branch. Based on the IVUS assessment of vessel diameter, a 3.5-mm balloon was chosen and expanded to 10 atm.

dian Coronary Atherectomy Trial (CCAT), were so high.[60,93,103,116-127] In vitro studies have shown that IVUS is very accurate in identifying the amount of material that is removed by DCA compared with histology.[128] When the angiographic results of DCA are compared with IVUS, an important lesson of this technology is revealed[129]: angiography tends to overestimate the debulking or atherectomy component of DCA. Examples that emphasize this observation are shown in Figs 16, 17,[130] and Fig 18.

It should be noted that when DCA is performed with IVUS guidance, the procedure is performed in an iterative fashion.[131] That is, after an adequate number of cuts with the DCA device, IVUS imaging is performed. The DCA device is then reinserted and directed to the quadrants that reveal residual plaque by IVUS. In addition, if IVUS reveals that a section of plaque has been removed from the artery wall and only the media and adventitia remain, then the DCA device is directed away from those quadrants.[132] Figure 19

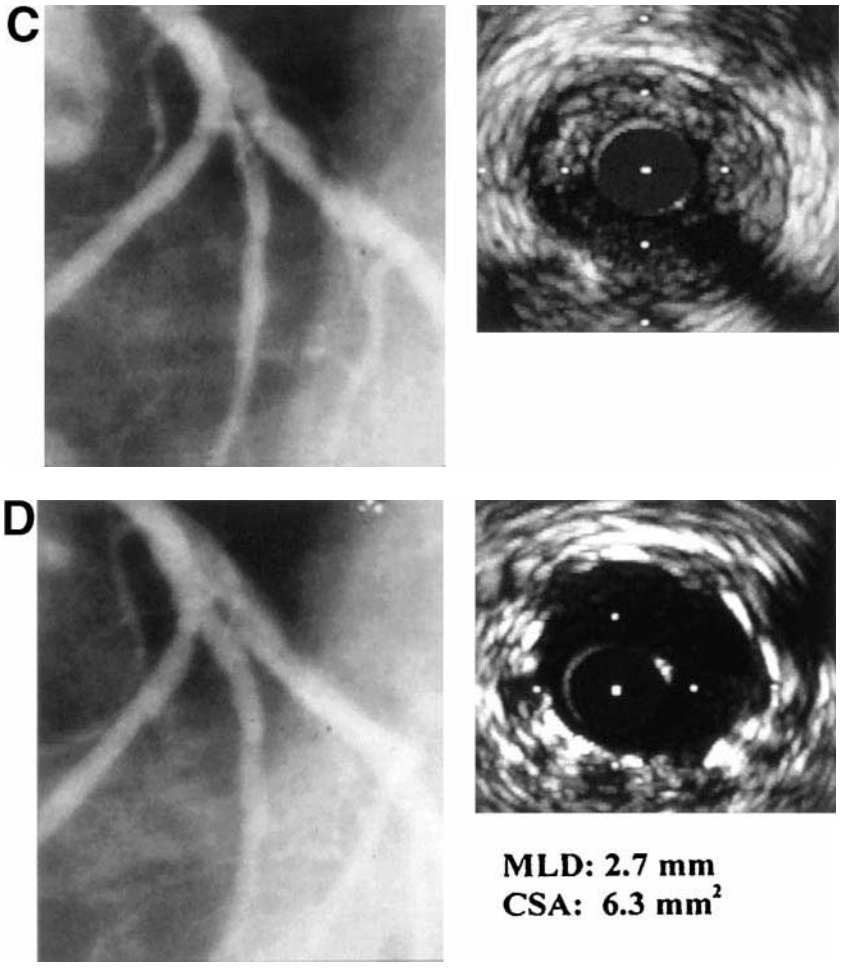

Fig 15. (Cont'd) Despite the use of a much larger balloon, there is significant recoil and the residual lumen is not much better than that obtained with the 2.5-mm balloon (C). The angiogram (left) appears to have a wider diameter because there are dissections behind the plaque into which contrast passes, thus making it seem that the diameter of the lumen is larger than it really is. Based on these IVUS observations (right) that this artery was not a "small vessel," a decision was made to proceed with coronary artery stenting. A Palmaz 104 stent was placed in the diagonal branch and expanded with the 3.5-mm diameter balloon at 14 atm (D). Not only does the angiogram (left) show a more satisfactory result, but the IVUS cross section (right) is now 2.7 × 3.0 mm and shows a circumferential patent lumen without dissections.

shows that IVUS can identify if the media or adventitia has been removed by DCA and this may not be evident by angiography. This method of IVUS-guided DCA therefore improves the safety of the procedure and maximizes the amount of material that is removed. In the CAVEAT Trial, IVUS imaging was not used, and it is likely that a greater amount of plaque was left behind than was appreciated by angiography.[60] Because the stretching effect was probably significant in that study, it may help explain why the restenosis rate was similar to the group treated with angioplasty alone (50% *v* 57%). With this new awareness, other DCA trials were designed to be more aggressive. In the Optimal Atherectomy Restenosis Study (OARS) Trial, directional atherectomy was optimized and the restenosis rate was reduced significantly to 29%.[133] In the Adjunctive Balloon Angioplasty following Coronary Atherectomy Study (ABACAS) Trial, IVUS imaging was used to guide the atherectomy so that a residual plaque cross-sectional area (CSA) of 47% was left.[134] This resulted in a restenosis rate of 21%.

These observations have led to a renewed interest in debulking lesions under IVUS guidance before stenting.

Stents and IVUS

The Influence of Stent Deployment on Subacute Thrombosis

When stents were initially used, the primary concern was the high rate of subacute stent thrombosis that inhibited the widespread use of coronary stents.[135-149] Initial observations of coronary stents with IVUS led us to an alternative explanation of why sub–acute stent thrombosis occurred. The first observation by IVUS was that

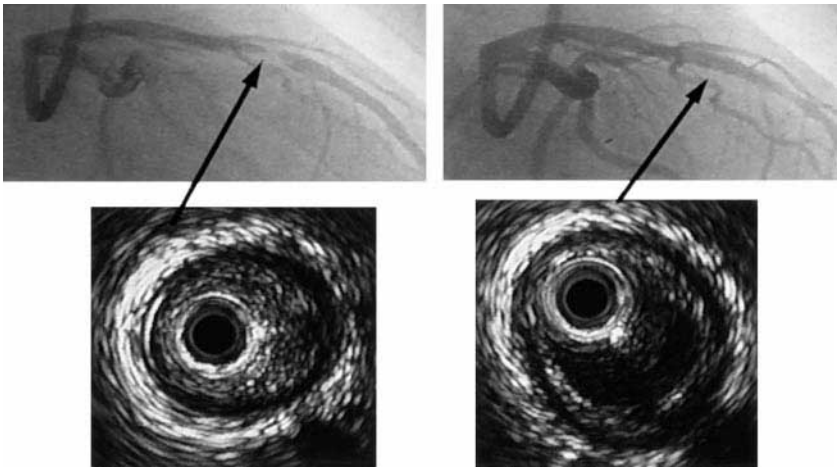

Fig 16. A severe stenosis in the mid LAD was successfully treated with DCA. The ultrasound image shows that before DCA (left) the catheter has been wedged into the plaque. Following atherectomy (right), the lumen is significantly enlarged, but measuring the diameter of the vessel from media to media, the vessel has also been significantly enlarged by stretching, similar to the effect of balloon dilatation.

there often was incomplete apposition of the metal struts against the arterial wall.[150] As shown in Fig 20, despite the use of a large balloon and a successful angiographic result, IVUS showed that the stent struts were not fully apposed to the arterial wall and were stranded in the middle of the lumen. By using a larger balloon, the stent struts were appropriately positioned against the arterial plaque. The second observation was that a number of stents were asymmetrically deployed, as shown in Fig 21. At the time this was thought to create turbulent flow and to be another initiating factor for subacute thrombosis. Based on these ultrasound observations, stents were redilated with either a larger balloon or at higher pressures to attempt to get a more symmetrical distribution of lumen shape.[151] The third observation provided by IVUS imaging was that many stents were inadequately expanded despite what appeared to be an appropriate angiographic result, as seen in Fig 22.

The Predictors and Outcomes of Stent Thrombosis (POST) registry[152] showed that 90% of patients with subacute thrombosis had IVUS-defined abnormalities, whereas only 25% of angiograms showed an abnormality that could explain why thrombosis occurred. These types of observations with IVUS led us to believe that the high incidence of subacute stent thrombosis was perhaps not as much due to any inherent thrombogenicity of the metal and the presence of a foreign body in the artery, as much as it was due to inadequate deployment with an insufficient lumen cross-sectional area resulting in diminished flow or turbulence that would promote thrombosis.

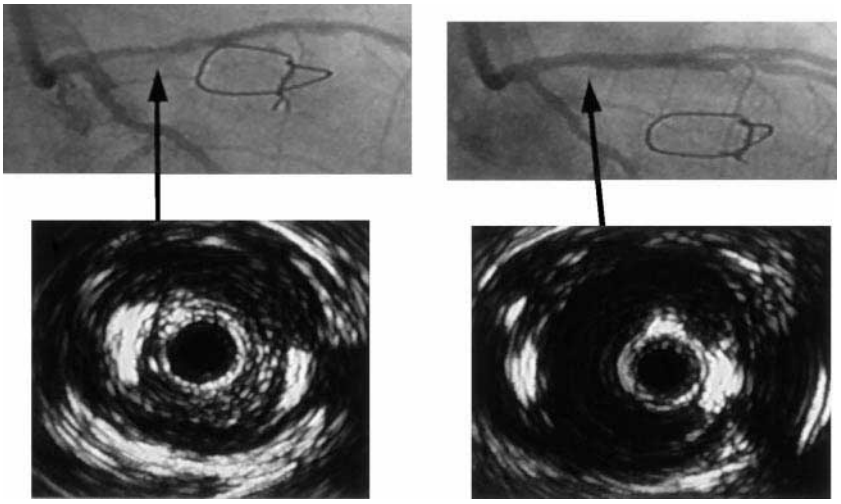

Fig 17. A successful DCA by angiography is shown. IVUS reveals that a significant amount of the plaque has been removed, but not the two calcified segments of plaque at the 9- and 3-o'clock positions.[130]

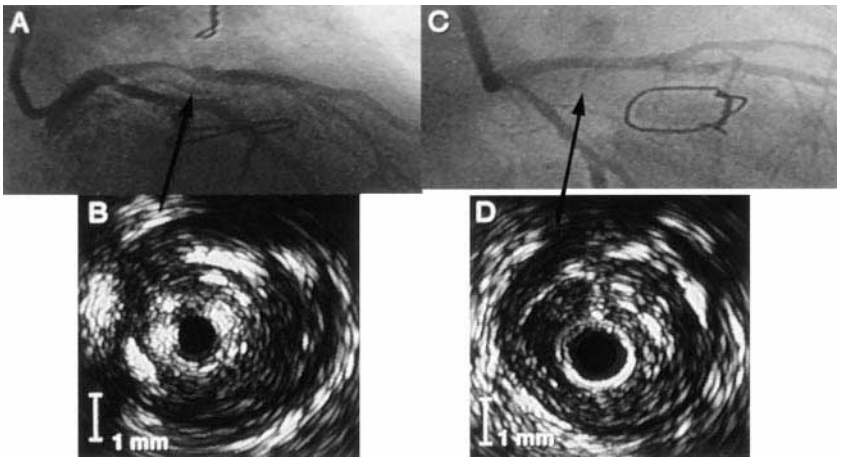

Fig 18. An example of a successful angiographic result with DCA is shown. In this case, the ultrasound study shows that only a very small amount of plaque has been removed despite multiple passes.

Coronary Artery Stenting with IVUS Guidance but Without Coumadin

When the Palmaz-Schatz and Gianturco-Roubin stents were first released, an attempt was made to diminish the catastrophic sequelae of subacute stent thrombosis by using an aggressive anticoagulation regimen.[61,143,153,154] This included heparinization following the procedure until an adequate elevation of the protime could be obtained with coumadin. This prolonged the hospital stay and produced major bleeding complications at the site of the arterial puncture.[155] Given the results of the ultrasound observations of the large lumen area that could be achieved with IVUS guidance, we withheld coumadin from the stented patients and slowly began to diminish the time of heparin treatment following the procedure. In addition, the antiplatelet regimen of aspirin was augmented with ticlopidine. The results of this study were published in 1995 and had a significant impact on the way that coronary artery stenting has since been performed.[156] By deploying stents with IVUS guidance, subacute thrombosis occurred in only 1.4% despite the absence of coumadin therapy or heparin following the procedure. Without the use of an aggressive anticoagulation regime, the vascular complication rate was significantly reduced to 0.6%. The hospital stay was decreased from an average of 5 days with coumadin therapy to 1 day. Moreover, the final minimum lumen diameter was markedly improved to 3.39 mm as compared with the results that were obtained without ultrasound guidance, such as the Stent Restenosis Study (STRESS) or Belgium Netherland Stent Investigators (BENESTENT) Trial, where the mean final Minimum Lumen Diameter (MLD) in the stent group was 2.45 mm and 2.48 mm, respectively.[61,62,157]

Using our approach, the overall angiographic restenosis rate at 6 months was 20%, and was 14% for single stents, which was significantly lower than 29% reported in the STRESS Trial.

The technique of larger balloons and higher pressure inflations to deploy coronary artery stents without subsequent anticoagulation was

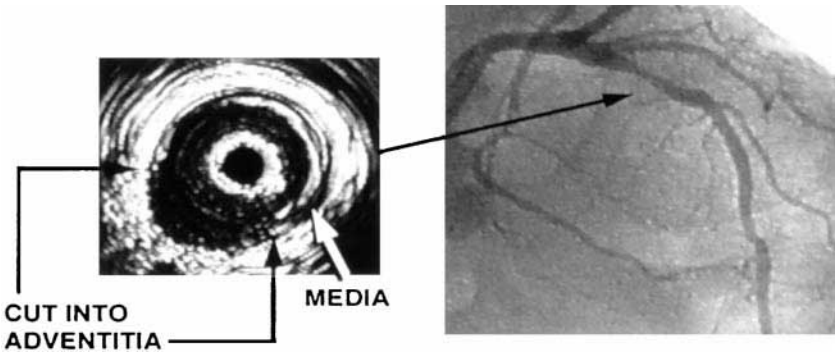

Fig 19. Removal of media and adventitia by directional atherectomy.

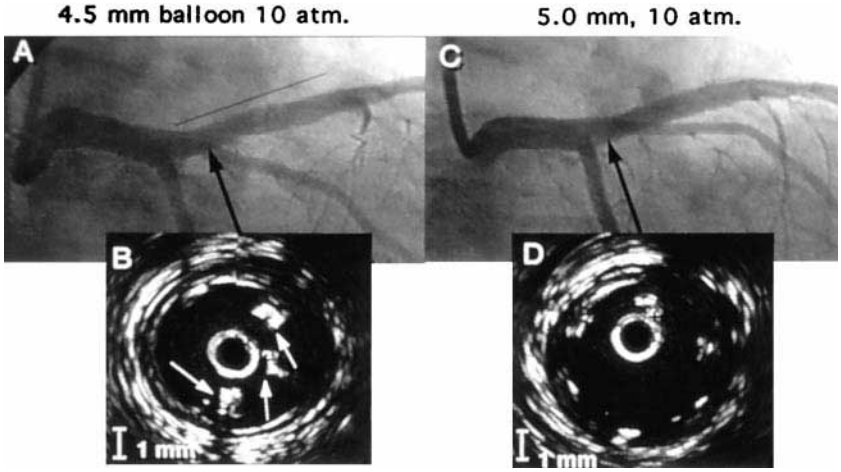

Fig 20. Incomplete stent apposition.

rapidly adopted by most interventional cardiologists. Subsequent papers showed a marked reduction in subacute stent thrombosis, vascular complications, and patient stay.[158-161] Several authors also reported excellent results using this balloon dilatation strategy without IVUS guidance to assess their results.[162-164] It now appears that IVUS imaging is not necessary to obtain a low incidence of subacute stent thrombosis.[165-167] There still are other potential advantages of using IVUS during stent deployment, the most significant of which is the influence of ultrasound guidance on restenosis, which is discussed next.

Can IVUS Improve Late Outcomes?

From a retrospective analysis of 2,343 stented lesions comparing IVUS and no-IVUS guidance,[168] the group with IVUS guidance had a larger final minimal luminal diameter and a smaller final percent diameter stenosis as well as a significantly lower restenosis rate (24% *v* 29%, $P = .03$). The recent Can Routine Ultrasound Improve Stent Expansion (CRUISE) Trial[169] also showed such an effect. The preliminary results of this trial showed a significant reduction in the need for lesion revascularization in the patients treated with IVUS guidance as compared with angiographic guidance (8.9% *v* 14.8%, $P = .004$). The preliminary results of the Angiography Versus IVUS-Directed Stent Placement (AVID) Trial[170] showed a 1-mm^2 increase in minimum stent area with IVUS guidance compared with angiographic guidance alone. These studies indicate that IVUS imaging can improve late outcomes by permitting a larger lumen to be obtained during stent implantation.

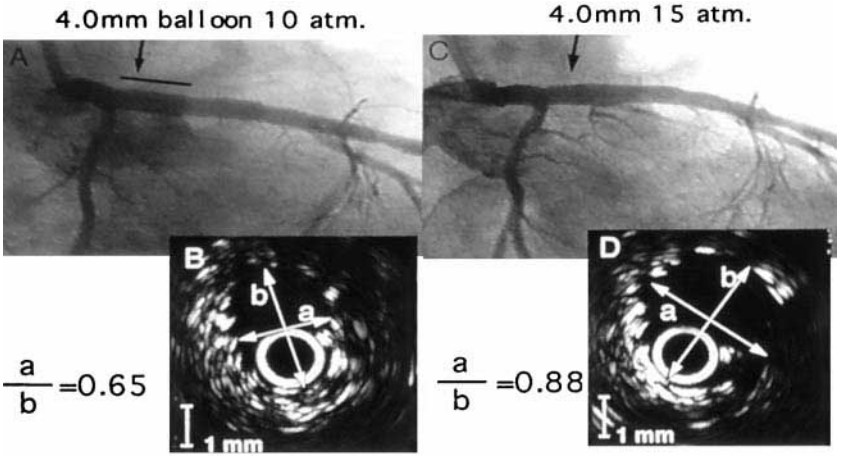

Fig 21. Asymmetric stent expansion.

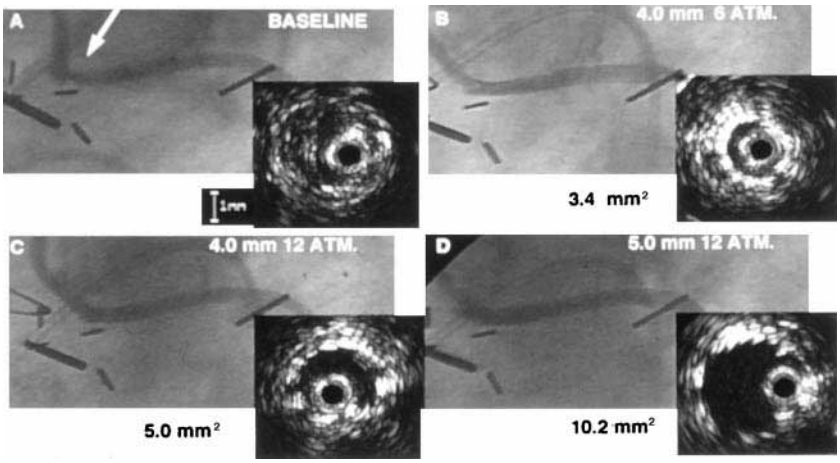

Fig 22. The baseline study reveals an ostial stenosis of a saphenous vein graft that is significant both by angiography as well as by ultrasound. Following inflation of the stent with a 4-mm balloon at 6 atm (which at the time was the recommended pressure) the angiographic result is significantly improved; however, the ultrasound cross-sectional lumen area was only 3.4 mm^2. By using higher pressures (12 atm) with the same balloon we were able to increase the dimensions to 5 mm^2. By using a larger balloon and higher pressure the final result was 10.2 mm^2. This use of IVUS-guided stent deployment increased the residual lumen cross sectional area 300% from 3.4 to 10.2 mm^2.

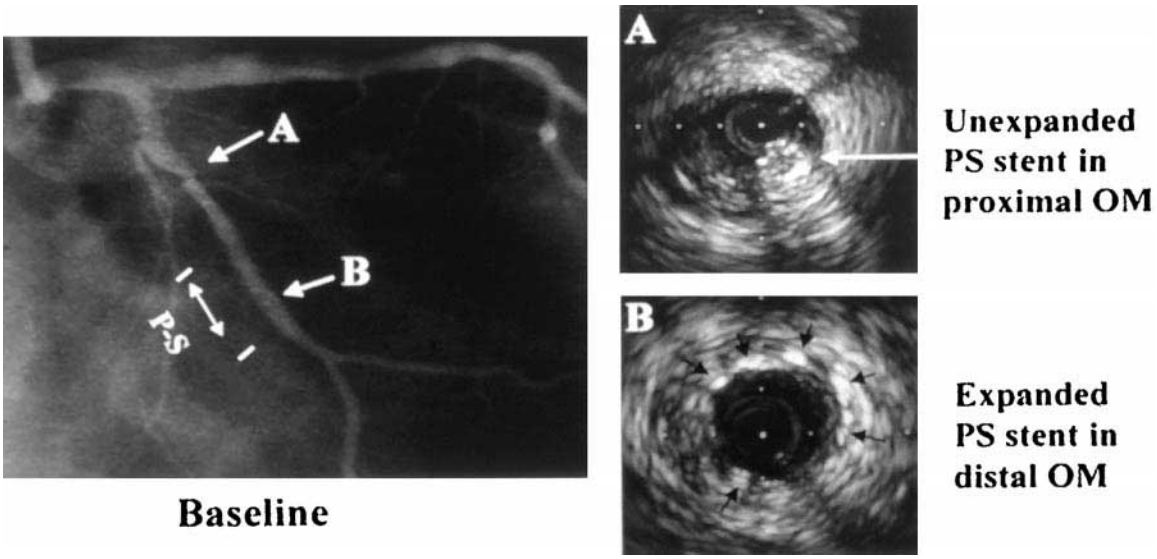

Fig 23. A Palmaz-Schatz stent was placed with great difficulty in the distal portion of the obtuse marginal artery. During the struggle to place a second Palmaz-Schatz stent in the proximal segment, the guiding catheter and guide wire suddenly flipped out of the artery. When the balloon was examined, the stent was not present. It was not known if the stent had been stripped off in the coronary artery or embolized in the aorta. After rewiring the artery, the ultrasound image (A) showed an unusual pattern where the echogenic stent struts were seen at the 4-o'clock position in a collapsed state to the side of the ultrasound catheter. For comparison, the IVUS image shown (B) reveals the circumferential struts of the adequately placed first Palmaz-Schatz stent in the distal section of the artery.

Undeployed Stents

One of the most dramatic examples of a case in which IVUS imaging has been essential for understanding complications that occur with coronary artery stenting is the discovery of a stent that has slipped off the delivery balloon and is sitting in the artery in an undeployed state. An example of this is provided in Figs 23 and 24.

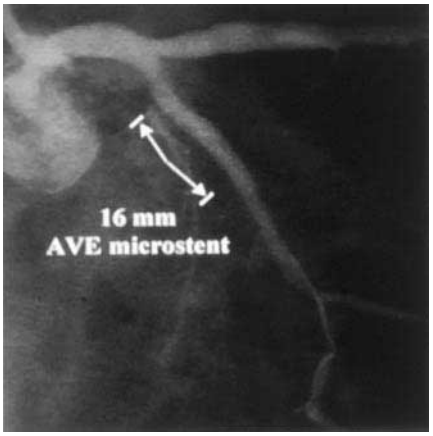

Fig 24. To treat the complication in Fig 23, a new 16-mm AVE stent was placed in the main lumen of the artery, external to the undeployed stent and was expanded with a 3.5-mm balloon at 10 atm. This compressed the Palmaz-Schatz stent to the side and provided adequate expansion.

Tissue Prolapse Through Stent Struts

IVUS can identify the presence of tissue prolapse through stent struts. Prolapse of atherosclerotic plaque into the lumen through stent struts may be a precipitating cause of subacute stent thrombosis or restenosis. This problem is rarely identified by angiography alone.

An example of this is shown in Fig 25.

Complex Anatomy During Stent Implantation

Coronary stenting reduces restenosis and clinical events in focal de novo lesions compared with balloon angioplasty.[61,62,157] However, when stents are implanted in complex lesion subsets, such as ostial lesions, lesions at bifurcations, or in the left main artery, bypass grafts, and small vessels, the process of stenting is technically challenging and restenosis remains a problem. IVUS provides important information in such situations and may facilitate the procedure or reduce the risk of complications.

Ostial Lesions

Aorto-ostial stenosis is a rare manifestation of multivessel coronary artery disease. The incidence varies between 0.13% and 2.7% of patients with angiographic coronary disease.[171-173] On the other hand, non–aorto-ostial stenosis is not an uncommon finding in patients with atherosclerosis.

Although the efficacy of surgical revascularization in patients with ostial stenosis is well recognized,[174] catheter-based coronary revascularization also has been applied successfully to this lesion subset. With improvements in operator experience, angioplasty technique, and evolution of equipment, the successful treatment of ostial lesions has evolved.

Aorto-ostial stenosis. The treatment of aorto-ostial lesions by conventional balloon angioplasty[175,176] and other devices, such as laser[177] or directional atherectomy,[178] has been limited by a low success rate and high incidence of restenosis. Coronary stenting is an attractive alternative for this subset of lesions because it provides the necessary scaffolding to support the artery.[179] However, preparing the lesion for a stent with balloon dilatation may be a significant challenge because these lesions tend to have a high incidence of calcification[180] or are very resistant because the balloon has to stretch against the longitudinal direction of the aortic wall. To address these issues, rotational atherectomy or directional atherectomy is frequently performed before stenting to debulk the plaque and prepare the entrance for the stent.

Stent implantation in the aorto-ostial location is technically challenging because of difficulties in seating the guiding catheter, obtaining adequate images to enhance stent placement, ensuring proper stent position to adequately cover the entire lesion, and preventing stent migration or embolization. Precise stent placement can be facilitated by using a stent that is clearly visible, such as the Palmaz biliary or MultiLink Duet stent. Moreover, the use of IVUS guidance is critical for optimum deployment and correct positioning during ostial lesion stenting. The ultrasound images are used to determine the media-to-media diameter of the vessel, which in

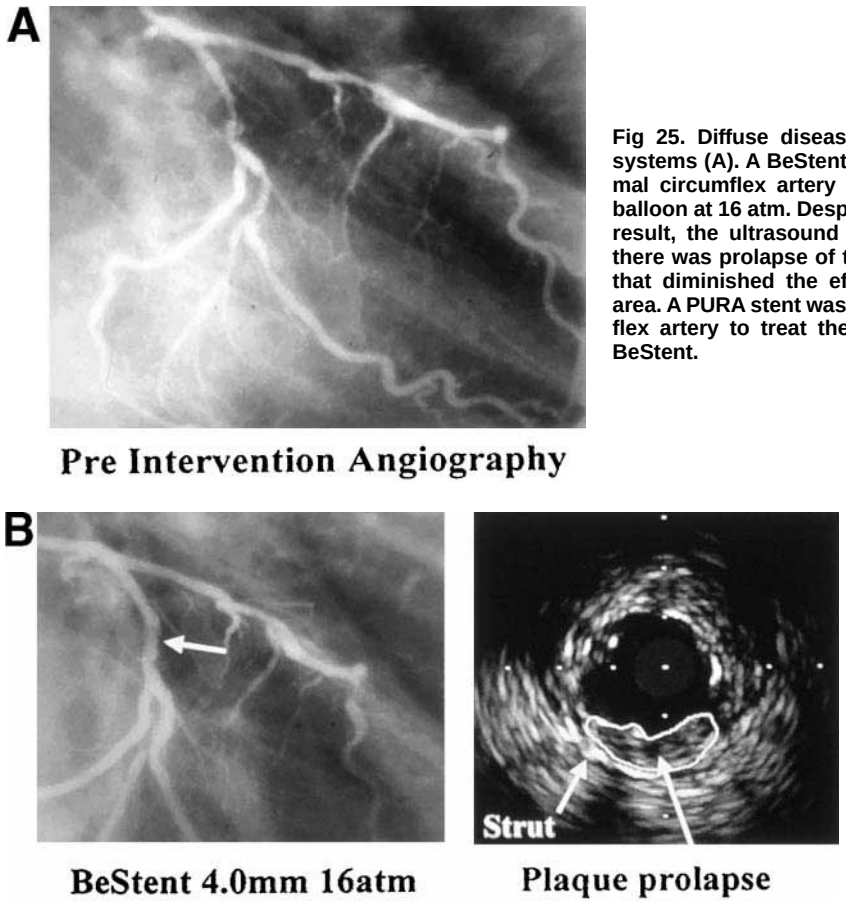

Fig 25. Diffuse disease in the LAD and circumflex systems (A). A BeStent stent was placed in the proximal circumflex artery and expanded with a 4.0-mm balloon at 16 atm. Despite a satisfactory angiographic result, the ultrasound image shown (B) shows that there was prolapse of tissue through the stent struts that diminished the effective lumen cross-sectional area. A PURA stent was placed in the proximal circumflex artery to treat the tissue prolapse through the BeStent.

turn allows us to choose the correct stent and balloon size. In addition, contrast can be injected under fluoroscopy during ultrasound imaging to correlate the exact ostium of the artery with the angiographic appearance in the view that we are going to place the stent. The ultrasound distinction between the aorta and the ostium of the artery is very obvious and is not obscured by the superimposed projection of the sinus of valsalva and the ostium of the artery as occurs with x-ray imaging. After the stent is placed and expanded to high pressure, the artery and stent are again interrogated with IVUS to confirm that the stent struts extend right up to the ostium or perhaps 1 mm beyond into the aorta. If the ostium appears compromised or the stent is not within 1 mm of the true ostium, then a second stent should be placed.

Another concern when stenting ostial lesions is the higher restenosis rate. The best approach for decreasing restenosis in ostial lesions should be to maximize the lumen cross-sectional area. This can be obtained by: (1) debulking the lesion with rotational atherectomy or directional atherectomy, (2) using a stent that has very high radial strength such as the Palmaz biliary stent, and (3) expanding the stent with an optimally sized balloon as determined by IVUS measurements of the media-to-media diameter.

An example of treating an aorto-ostial lesion is presented in Figs 26 and 27.

Non–aorto-ostial stenosis. Although stenoses of the initial portion of the LAD or circumflex arteries are referred to as ostial lesions, these differ somewhat from the true aorto-ostial lesions described above. The obvious difference is that the takeoff of these vessels is not from the aorta itself so that the ostial LAD or circumflex lesion usually does not have the same resistance as a true aorto-ostial lesion. The other major difference between these two sets of lesions is that the LAD or circumflex ostial lesion frequently involves the bifurcation either because the disease extends into the bifurcation, although it may not be apparent by angiography, or placement of the

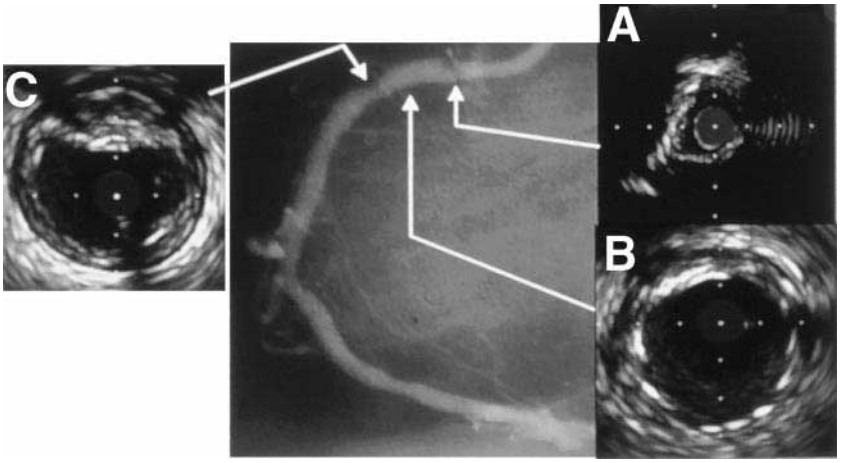

Fig 26. This case shows a right coronary artery in which a stent was deployed for a proximal stenosis. After placement of a 15-mm long ACS MultiLink stent expanded to 14 atm with a 4.0-mm balloon, there is an irregular linear density at the interface of the guiding catheter and coronary artery. The linear density is not very long, which makes it difficult to assess. The IVUS image (A) at the ostium shows that the lumen is oblong in shape with intense superficial calcification. The lumen at the aorto-ostial inlet measures only 1.5 × 2.0 mm. The proximal RCA portion covered by the stent was adequately expanded with a lumen of 4.0 × 3.5 mm by IVUS (B). Distal to the stent, there is some lumen narrowing, but the eccentric lumen is adequate at 3.5 × 2.3 mm (D). Five millimeters distal to the stent, the artery is quite large and measures 5 × 4 mm in diameter (media to media).

stent too proximal may entrap the other vessel. In addition, retrograde dissection may cause complications at the bifurcation and involve the branch vessel. The similarities in treating the ostial LAD or circumflex lesions compared with aorto-ostial lesions are that precise placement of the stent may be difficult, and that both sets of lesions respond better to debulking with directional atherectomy, or rotational atherectomy if the arteries are calcified. Figures 28, 29, and 30 provide dramatic examples of how IVUS may be critical in the treatment of ostial lesions.

Bifurcations

The treatment of stenoses at a bifurcation remains one of the most challenging lesion subsets in coronary angioplasty. Bifurcation lesions carry a risk of side branch occlusion because of plaque redistribution or so-called "plaque shift" across the carina of the bifurcation. The risk is increased if there is an eccentric lesion at the bifurcation site and a stenosis in the ostium of the side branch.[181,182] To diminish this plaque shifting, the "kissing" balloon technique was developed.[183]

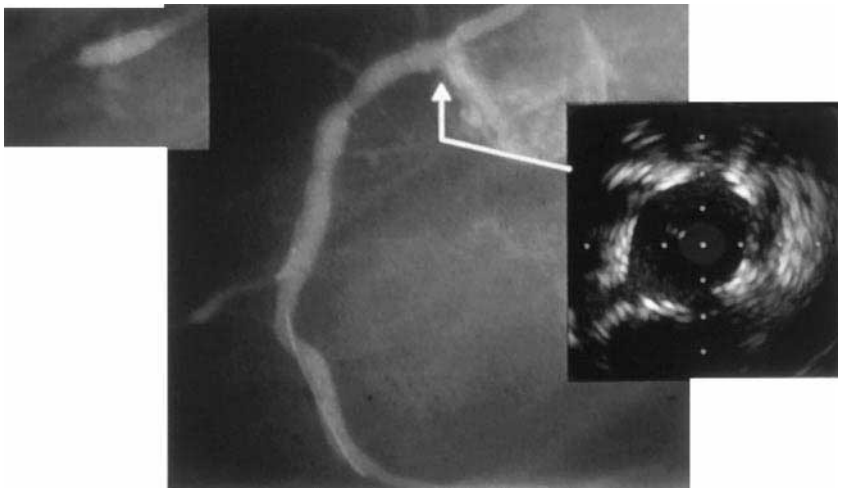

Fig 27. Based on this ultrasound evaluation, a Palmaz 104 biliary stent was placed on a 4.5-mm Chubby balloon and deployed at 14 atm at the ostium of the right coronary artery. The final angiogram shows an expanded ostium, and the ultrasound study shows that the lumen at the ostium is 3.5 × 3.0 mm.

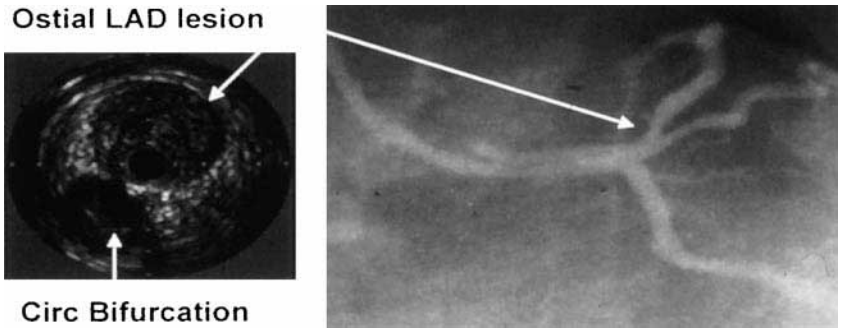

Fig 28. The angiogram at baseline revealed an eccentric stenosis at the ostium of the LAD that was not dramatic by angiography. However, the IVUS exam showed that there was extensive eccentric plaque that surrounded the ultrasound catheter and extended up to the bifurcation with the circumflex artery. In addition, the takeoff of the LAD was tortuous, which could make placement of a stent more difficult. A Palmaz-Schatz stent was hand crimped onto a balloon and was placed in the ostium of the LAD under fluoroscopic guidance.

However, the results with balloon dilatation of bifurcation lesions still had a high incidence of complications, suboptimal results, and restenosis.[181,184-186] Treatment of bifurcations with directional atherectomy (without stenting) has been shown to improve the immediate procedural outcome compared with balloon dilatation alone, but the incidence of restenosis remains high.[187] The use of coronary stents has improved the treatment of bifurcation lesions, but it is technically challenging and there is still a high incidence of compromising the branch vessel.[188-190] Stent implantation on both the main vessel and the side branch, which is called "kissing stents," is a useful technique for maintaining maximum expansion of both vessels. The use of two stents minimizes lumen loss of one side during expansion of the other branch.[191] The four main techniques used for bifurcation stenting (the coil stent, the "T" stent, the "Y" stent, and the "V" stent technique) have been described step by step with their advantages and disadvantages.[192]

Whatever technique is selected, IVUS guidance is of critical importance for optimizing the result. Bifurcation lesions are very difficult to examine completely despite multiple angiographic projections because of vessel overlap. IVUS imaging can facilitate placement of the stents and confirm

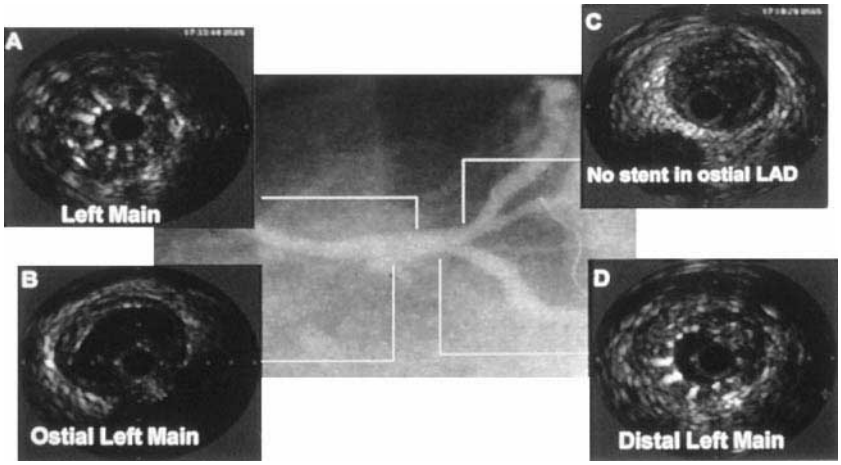

Fig 29. An acceptable angiographic result was obtained. IVUS was then performed to confirm that the stent had been placed precisely at the ostium without obstructing the circumflex artery. The ultrasound images provided a surprise. The reflections from the metallic stent struts were seen in the mid (A) and distal left main artery (D) and no stent struts were seen at the ostium of the LAD (C). In addition, the stent struts were only mildly expanded in the distal left main and were not expanded at all in the mid left main. This indicates that the stent had slipped off of the balloon and migrated to the more proximal left main artery.

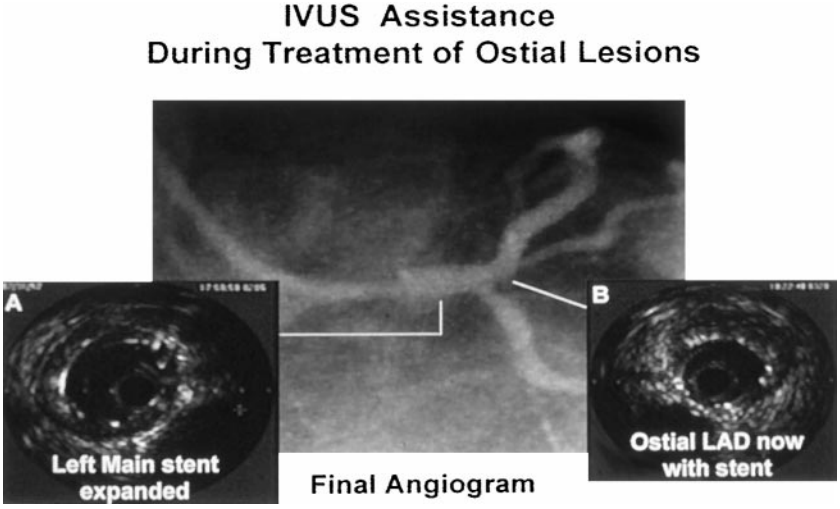

Fig 30. To correct the problem in fig 29, a 4.0-mm balloon was positioned across the stent and was expanded in the left main coronary artery to secure the migrated stent. In addition, a second Palmaz-Schatz stent was cut in half, and this half stent was placed into the ostium of the LAD and expanded with a 3.0-mm balloon shown as documented by IVUS.

optimal lesion coverage, stent expansion, and strut apposition.[192] In addition, if feasible, bifurcation lesions should be pretreated with rotational atherectomy, or directional atherectomy, to diminish plaque shifting. The choice of device is aided by the use of preintervention IVUS imaging according to the composition and distribution of plaque and the size of the vessel. Compression of the adjacent branch is enhanced after stenting because of the absence of mural support at the carina. In addition, the larger balloon size and high pressure applied to achieve large luminal gain and optimal stent expansion may compromise the ostium of side branches in bifurcation lesions.[192] On occasion, a three-dimensional reconstruction of the IVUS images obtained on pullback may be helpful for understanding the anatomy immediately surrounding a bifurcation. An example of this is provided in Fig 31.

Left Main Artery Stenting

In contrast to "protected" left main (LM) stenosis, that is, at least one patent coronary artery bypass graft supplying the left coronary artery system, "unprotected" LM stenosis has been considered a contraindication for percutaneous catheter-based revascularization. During balloon angioplasty there may be severe hemodynamic compromise, or disastrous consequences following abrupt vessel closure. Recent advances in stent implantation techniques[156] and poststent antithrombotic regimens[193,194] have caused some centers to reconsider the role of percutaneous treatment of patients with unprotected LM stenoses. Several groups have reported acceptable short- and long-term results in treating LM stenosis.[195-202] IVUS is an important adjunctive imaging modality for LM intervention. Despite its clinical significance, LM disease may not be accurately evaluated by coronary angiography alone.[203,204] In addition, stenting the LM lesion has several unique characteristics. By IVUS, the LM is frequently 5 mm in diameter (media to media) despite the narrowed appearance by angiography. Compared with the rest of the artery, there is a much larger amount of plaque per cross-sectional area. Because the risk of restenosis is critical when stenting the LM, debulking the lesion before stenting is preferred, which not only facilitates deployment of the stent but should lower the restenosis rate by half. IVUS provides accurate sizing of the LM and visualizes the amount of plaque that may need to be removed. Operators must pay attention to the differences between placing a stent at the aorto-ostial junction, in the body of the LM, or if the lesion encompasses the bifurcation of the LAD and circumflex arteries. Even though an angiogram shows a stenosis isolated to the body of the LM, there may be involvement of the bifurcation that is not appreciated until IVUS is performed. The information that IVUS provides is important in planning the approach to this high-risk lesion subset. Figure 32 is an example in which IVUS enabled optimal stent implantation for a LM trunk stenosis.

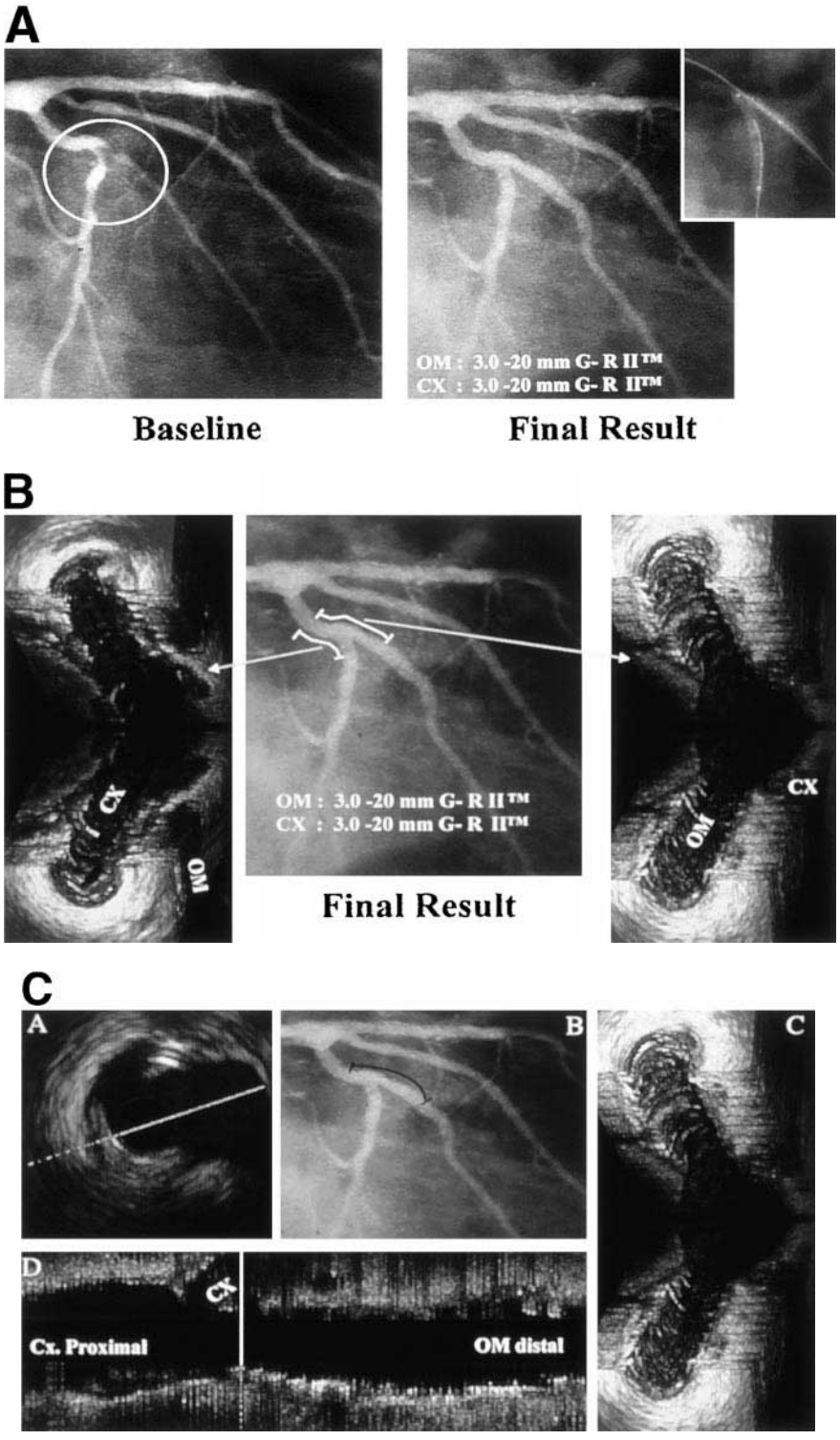

Fig 31. The bifurcation of this circumflex and obtuse marginal branch was treated with two Gianturco-Roubin II stents, each 20 mm long (A). IVUS imaging was obtained in each branch and three-dimensional reconstructions of the pullback from the circumflex artery and obtuse marginal artery are shown on the left and right hand panel (B), respectively. IVUS images can be presented in a variety of ways (C), to more clearly define the anatomy at a bifurcation.

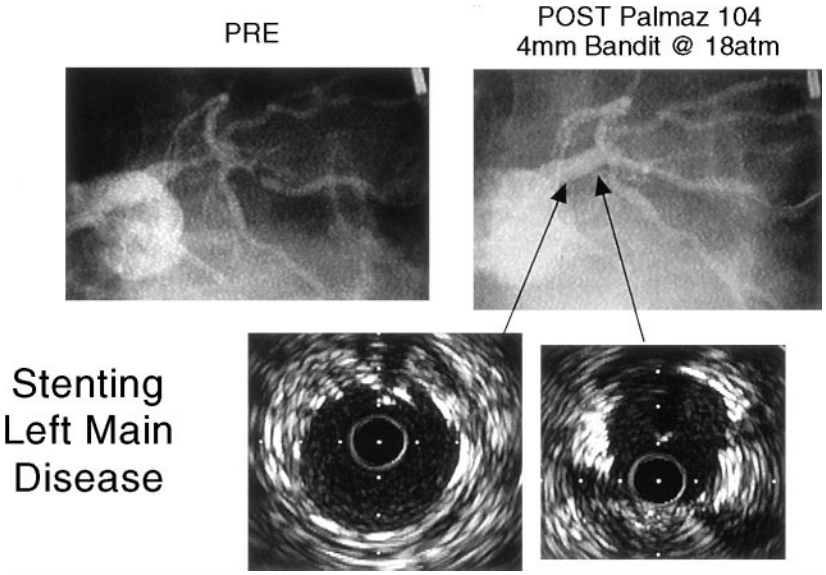

Fig 32. The left main artery is severely narrowed in the mid to distal segment, which then enters into a confluence from which 4 vessels emanate like spokes in a wheel. Because each of these vessels was comparatively small and had a sharp angle relative to the left main, it was elected not to debulk the left main trunk. After placing an intraaortic balloon pump, the left main was predilated with a 4.0-mm balloon. A Palmaz 104 stent was deployed in the left main at 18 atm. Despite a satisfactory angiographic result, the IVUS images show that the distal section was asymmetric and underexpanded. Repeat dilatation increased the lumen diameter to 3.5 × 3.8 mm.

Bypass Grafts

The treatment of patients with obstructive disease in coronary artery bypass grafts poses a challenge of increasing magnitude as the population of patients who have undergone bypass surgery continues to grow.

Saphenous vein graft. Within a decade after surgery, half of all saphenous vein bypass grafts have severe atherosclerotic disease.[205-209] Management of graft disease is problematic, because repeat surgery entails substantial risk, and the results of conventional angioplasty have been disappointing.[176,210-216] However, recent studies have suggested more favorable results in diseased vein grafts.[217-221] As compared with repeat coronary artery bypass grafts, it was reported that catheter-based revascularization procedures have similar efficacy for the patient with vein graft disease in the new device era and that the choice of therapy should consider patient preference as well as clinical and angiographic suitability.[222]

Although some authors indicate that revascularization strategies in saphenous vein grafts are less often influenced by IVUS than in native arteries,[223] other authors have shown that IVUS provides useful information when applied to this lesion subset.[224] Vein grafts may have variations in their external width that lead to an underestimation, compared with angiography, of the diffuseness of the disease.[225] IVUS enables accurate device sizing by measuring the true diameter of the graft at the lesion site. This is particularly useful for appropriate sizing of stents in these large conduits. One report showed that with angiographic guidance, only 9% of stents were optimally expanded to match the reference cross-sectional area.[226] IVUS examination may identify lesions at high risk of rapid progression or may induce referral of patients to surgery who have diffuse vein degeneration with friable plaque (low echoreflectivity with irregular borders).[223] The distinction between degenerated and fibrotic vein grafts is important. Even if distinct thrombi are not seen, degenerated lesions may have embolic potential. Lytic therapy and atheroablative techniques (transcutaneous extraction catheter [TEC], DCA, or laser atherectomy) are important adjuncts in the transcatheter approach to degenerated lesions. If degenerated lesions have intraluminal thrombus, new thrombectomy catheters such as the Angiojet (Possis, Minneapolis, MN)[227,228] or Hydrolyser (Cordis Europa NV, Roden, The Netherlands)[229] might help remove nonorganized thrombus.

Of the various stents currently available, the Wallstent has been found to be a useful device for treating saphenous vein graft stenosis.[230] Because the disease process in vein grafts tends to be diffuse and the conduits are long, the self-expanding Wallstent is ideal for this application. In addition, the Wallstent comes in variable lengths and diameters. Covered stents such as an

autologous saphenous vein-covered stent[231] or polytetrafluoroethylene (PTFE)-covered stent[232] may have additional advantages in treating degenerated lesions. Covered stents may prevent prolapse of friable tissue through the stent struts and thereby decrease embolization. Preintervention IVUS examination can assist in making these critical decisions.

Small Vessels

One of the important anatomic factors of restenosis after balloon angioplasty, DCA, or stenting is vessel size because the restenosis rate is inversely related to the reference vessel diameter.[62,233,234]

The advantage of stenting instead of using balloon angioplasty in small vessels is still controversial. A retrospective study suggested that balloon angioplasty was equivalent to stents in patients with small vessels.[235] On the other hand, two studies indicated that stenting was more efficacious than balloon angioplasty for small vessels between 2.6 and 3.0 mm in diameter.[236,237] Although the immediate success rate and complications in stenting small vessels may be equivalent to those found in larger vessels, the 6-month restenosis rate is higher in smaller vessels (19.9% *v* 32.6%).[238,239] The fact that intimal hyperplasia at follow-up was independent of stent size might explain the high restenosis rate in small vessels after stenting.[240-242]

IVUS may potentially improve the outcome of stenting small vessels. Akiyama[238] analyzed patients who received coronary stents in a small (less than 3.0 mm) artery with or without IVUS guidance. The restenosis rate was significantly lower when IVUS guidance was used (29% with IVUS guidance *v* 38% without, $P = .04$). The use of IVUS guidance was thought to facilitate decision making in terms of balloon sizing, especially in angiographically small vessels that might in fact be large vessels with diffuse atherosclerosis. It was hypothesized that a greater balloon-to-vessel ratio used in the small-vessel group might have led to greater wall injury and more reactive neointimal proliferation followed by a higher restenosis rate.[243] However, this was recently denied by several studies.[238,242] The discrepancy between angiography and IVUS of accurately determining reference diameter is shown in Fig 33.

Debulking Before Stenting

Restenosis remains a problem when stents are implanted in complex lesion subsets, such as long lesions,[244,245] ostial lesions,[179,246,247] chronic total occlusions,[248-252] and bifurcation lesions.[253] Restenosis after implantation of slotted tube stents is

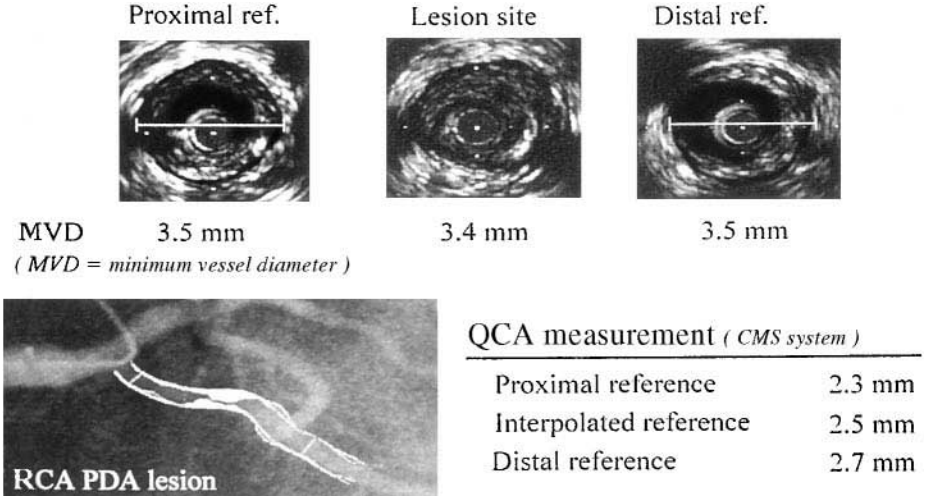

Fig 33. The angiogram shows the results of QCA measurement of a posterior descending artery with a severe stenosis. The proximal reference was measured as 2.3 mm and the distal reference was 2.7 mm, giving an average reference of 2.5 mm. However, by IVUS, the media-to-media diameter was 3.5 mm, both proximally and distally. Based on this observation, the decision was made to debulk the lesion with rotational atherectomy. A larger burr (2.0 mm) and a larger balloon (3.25 mm) were used than would have been chosen if the decision were based on angiographic guidance. In addition, a stent was placed with greater expansion than would be deemed appropriate based on the angiographic measurement alone.

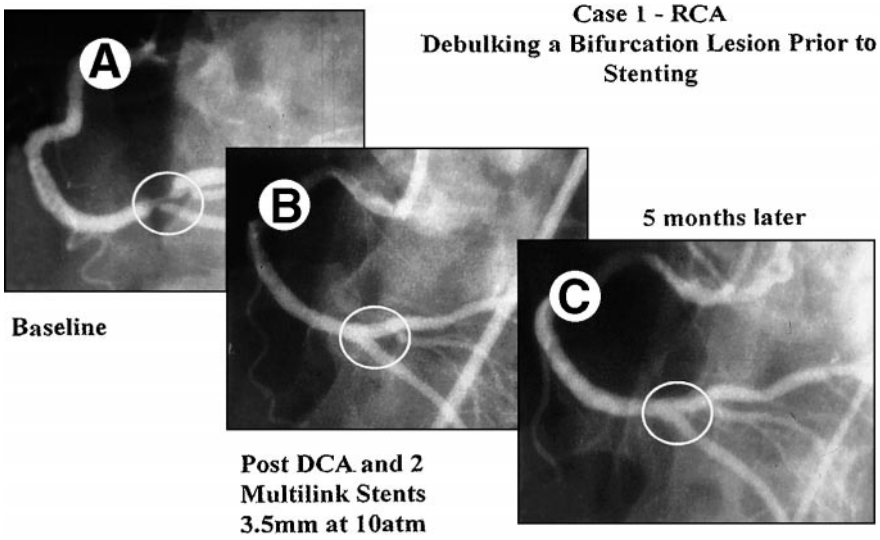

Fig 34. The distal RCA lesion is located at the bifurcation of the PDA and posterolateral (PL) branch (A). The interpolated QCA reference diameter was 2.87 mm (toward the PDA) and 2.88 mm (toward the PL). Two high-support guide wires were used to cannulate both the posterior descending artery (PDA) and PL branches. Directional atherectomy was then performed using a 7 French GTO cutter toward the PDA and PL. Two MultiLink stents were implanted at the bifurcation, and both stents were expanded simultaneously using the kissing balloon technique (balloon diameter 3.5 mm inflated at 10 atm in both branches). The final result is shown (B). There was no significant restenosis at the 5-month follow-up angiogram as shown (C).

mainly due to neointimal proliferation.[254] Observational IVUS data indicate that a larger plaque burden, either before[241,255] or after stenting,[256] leads to a higher rate of late lumen loss after stenting. In addition, angiographic data[257] indicate that after stent implantation, restenosis tends to occur at the original lesion site (where the plaque burden is largest). Based on these observations, it was proposed that removal of atherosclerotic plaque before stenting would lead to a reduction in neointimal hyperplasia, thereby reducing the incidence of restenosis. Recently, several studies have supported this hypothesis. Two different debulking devices were applied before stenting according to the lesion characteristics: directional atherectomy for noncalcified large vessels[258-261] and rotational atherectomy for calcified and/or small vessels.[262-264]

DCA Plus Stenting

Currently, DCA is the most effective device to remove noncalcified plaque,[133] thus transforming the atherosclerotic arterial wall to a thinner structure that is more compliant to dilatation.[265] Even with optimal atherectomy, compared with PTCA, restenosis remains about 30% with no difference in the need for repeat revascularization at 1-year

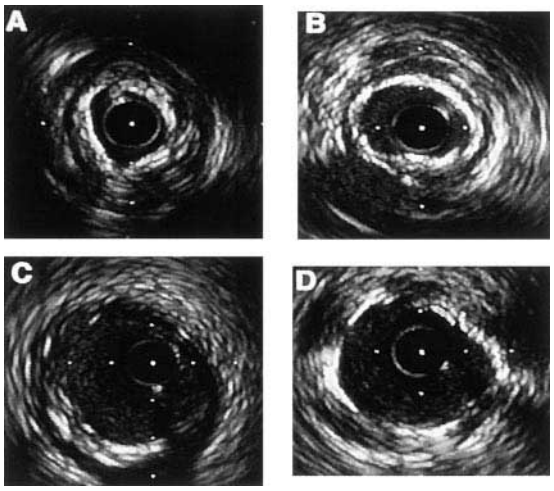

Fig 35. Using IVUS imaging before the intervention, tissue characterization reveals significant calcification at the lumen plaque interface (A). Therefore, progressive rotational atherectomy burrs were used from 1.5 mm to 2.5 mm (B). Although the lumen was now slightly larger than 2 mm in diameter, the vessel size measured at the media was greater than 4 mm. Based on this IVUS observation, directional atherectomy was performed with a 7 French cutter, which removed a significant amount of plaque (C). At this cross section, the lumen measured 7.3 mm^2 and the area bounded by the media measured 15 mm^2, giving a lumen-to-vessel ratio of 49%. After removing the bulk of this plaque, a Crown stent was deployed on a 4-mm balloon at 16 atm. The final dimensions of the lumen were 3.0 × 3.5 mm or 8.1 mm^2 (D).

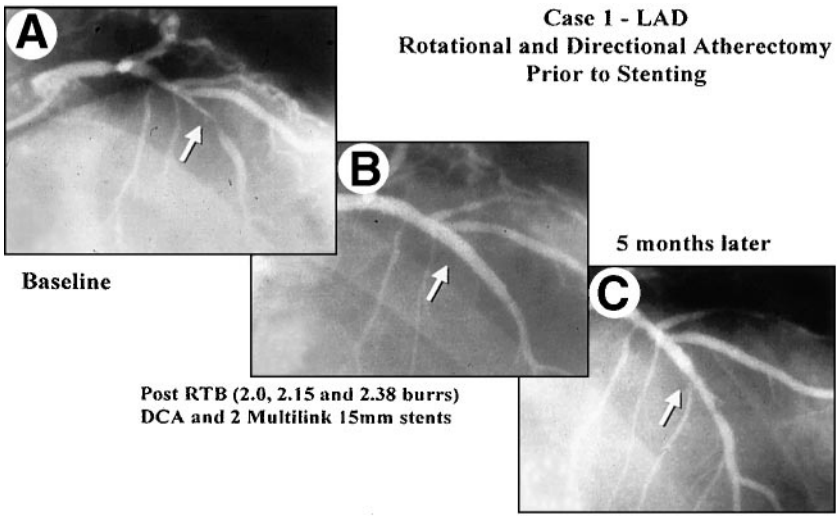

Fig 36. The lesion in the proximal LAD was calcified on angiography and measured 30 mm in length with a reference diameter of 2.98 mm (A). Preintervention IVUS was attempted; however, the IVUS catheter could not cross the lesion. Rotational atherectomy was then performed using a stepped burr approach (2.0, 2.25, and 2.38 mm). IVUS imaging postrotablation showed a large residual plaque burden. Therefore, DCA was then performed using a 7 French GTO cutter. Two MultiLink stents were implanted and expanded using a 3.5-mm balloon inflated at 11 atm (B). Follow-up angiography was performed at 5 months. There was no evidence for restenosis (C).

follow-up.[266] Late lumen loss after DCA has been shown by IVUS to be the result primarily of late arterial constriction in addition to neointimal hyperplasia.[112,113]

Therefore, the failure of stand-alone stenting or stand-alone DCA to reduce restenosis in complex lesion subsets suggested the need to explore the synergistic role of combining both techniques to reduce restenosis. The hypothesis is that plaque removal with DCA before stenting may lower the intensity of late neointimal hyperplasia, reducing the incidence of in-stent restenosis. This hypothesis has been supported by several recent studies that report a better early and late outcome for the DCA-plus-stenting group than the stenting-alone group.[258-261]

This DCA-plus-stenting approach may be optimized by using IVUS to guide the atherectomy cuts, similar to the procedure outlined in the OARS Trial.[133] The data of the Stenting after Optimal Lesion Debulking (SOLD) Registry[258] showed that the lower the residual plaque after DCA, the lower the loss index will be, with an amazing restenosis rate below 5% in the group that achieves an optimal removal of plaque burden using ultrasound guidance.

Figure 34 shows the use of directional atherectomy at a bifurcation to optimize the placement of two stents using IVUS guidance.

Rotational Atherectomy Plus Stenting

Rotational atherectomy is the preferred strategy to ablate calcified plaque.[267] Despite the high procedural success rate, significant restenosis rates of 37% to 57% were observed after stand-alone rotational atherectomy.[268,269] A recent histopathologic study showed that the presence of calcium is a powerful predictor of the amount of plaque burden in atherosclerotic arteries.[270] In addition, in vivo IVUS ultrasound studies have shown that coronary calcium is an important determinant of decreased wall compliance,[271] and it leads to a high incidence of dissections when these lesions are dilated[27] and a high rate of suboptimal expansion when stents are used.[272] It was hypothesized that pretreating the lesion with atheroablative techniques to reduce the calcified plaque burden would improve vessel wall compliance. This in turn would optimize stent expansion and consequently lower the restenosis rate. This hypothesis was supported by recent studies.[262-264] These authors showed that adjunctive rotational atherectomy before stenting (rotastenting) for calcified or undilatable lesions improved not only the procedural result but also the late outcome. It was also shown that lesion morphology evaluated by IVUS before stent placement identified lesions with a greater likelihood of

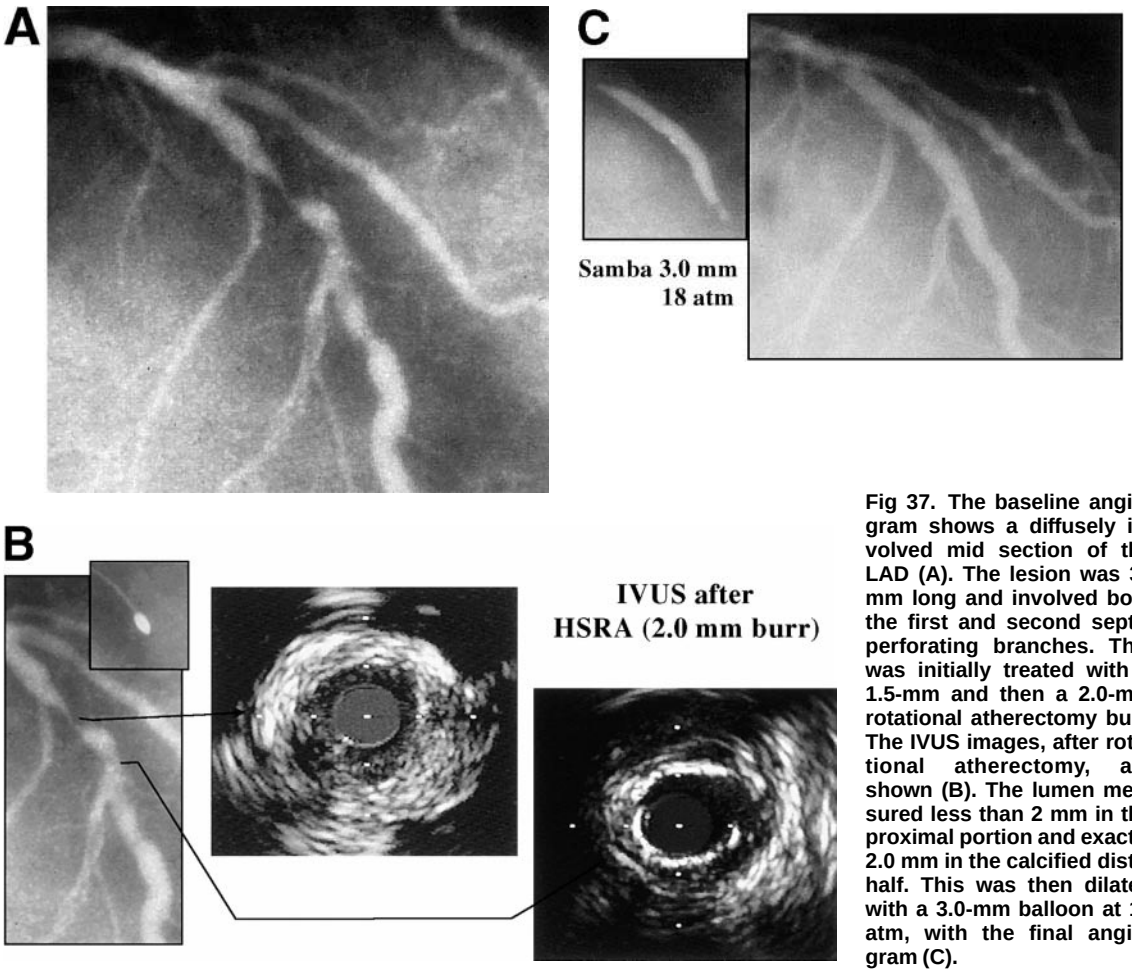

Fig 37. The baseline angiogram shows a diffusely involved mid section of the LAD (A). The lesion was 30 mm long and involved both the first and second septal perforating branches. This was initially treated with a 1.5-mm and then a 2.0-mm rotational atherectomy burr. The IVUS images, after rotational atherectomy, are shown (B). The lumen measured less than 2 mm in the proximal portion and exactly 2.0 mm in the calcified distal half. This was then dilated with a 3.0-mm balloon at 18 atm, with the final angiogram (C).

eccentric stent expansion and a smaller poststent MLD.[264] Therefore, preintervention IVUS can identify which lesions should be rotablated before stenting.

It remains unclear how aggressively rotational atherectomy should be performed before stenting. Using rotational atherectomy alone, a higher target lesion revascularization rate was reported (25%) when a burr/vessel ratio greater than 0.85 was used.[273] This effect was presumably due to the increased vessel trauma produced by the oversized burr. The use of a coronary stent might eliminate the chronic shrinkage triggered by rotablation with an oversized burr. Aggressive rotablation before stent placement would reduce the plaque burden and improve vessel compliance, and thus possibly reduce the late lumen loss associated with calcified lesions, similar to those reported for noncalcified lesions treated with DCA plus stenting.[258] IVUS provides more precise information than angiography about the amount and position of calcification, residual plaque burden, and vessel size of the target lesion. The use of IVUS in a repetitive process to image the artery before the intervention, after sequential atherectomies, and following stent insertion facilitates the procedure and improves the final lumen cross-sectional area within the stent zone.

A case example of the iterative use of IVUS to guide the atherectomy process is shown in Fig 35.

An example where IVUS guidance of rotational atherectomy plus directional atherectomy was used to optimize stent placement in the LAD is shown in Fig 36.

PTCA Provisional Stenting

Although intracoronary stenting represents the only currently available strategy shown to limit both clinical and angiographic restenosis,[61,62,274]

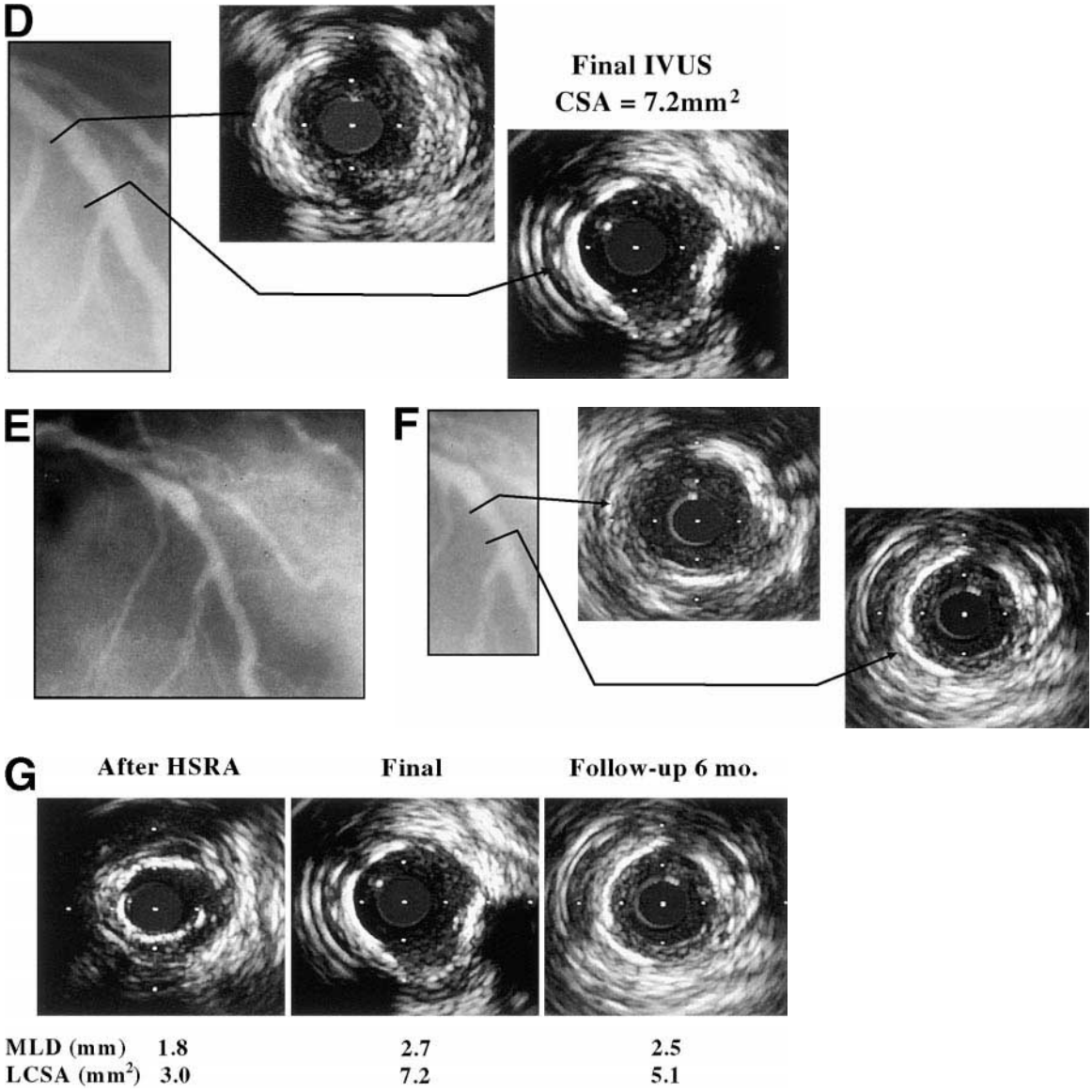

Fig 37. (Cont'd) Following rotational atherectomy and balloon dilatation, the final examination shows an adequate lumen cross-sectional area of 7.2 mm² (D). Based on these ultrasound measurements, a decision was made not to place a stent in this artery. The follow-up angiogram obtained 6 months after the procedure shows patency of the vessel with minimal restenosis (E). The angiographic results are confirmed by the follow-up IVUS study (F). These sequential changes in the IVUS images after initial rotational atherectomy, final balloon dilatation, and the follow-up are summarized (G).

it continues to be accompanied by several limitations. Stents are costly[155,275] and difficult to use with some complex lesion subsets such as bifurcation lesions,[188-190,192] lesions in small vessel,[235,238,239] and diffuse long lesions.[168,276] Most importantly, stents have engendered a new and difficult-to-treat entity of in-stent restenosis. In addition, there are many times when balloon dilatation alone provides an adequate long-term result. To address these issues, the strategy of "provisional stenting" has been developed.[277] In this method, an attempt is made to use balloon dilatation alone. IVUS guidance is used to choose the balloon size to obtain the best possible angioplasty result in terms of lumen cross-sectional area. However, if ultrasound imaging

reveals an inadequate lumen or the presence of a dissection that compromises the lumen, then a stent is placed electively.

Several studies have shown that IVUS can provide essential information during the provisional stenting procedure. In the CLOUT Pilot Trial,[74] Stone reported that the early angiographic and clinical results of IVUS-guided PTCA without stenting were promising. On the basis of the vessel size and extent of plaque burden in the reference segment evaluated by IVUS, 73% of the lesions required larger balloons even after achieving an optimal angiographic result (final balloon/artery ratio = 1.30 ± 0.17). The success rate of IVUS-guided PTCA was 99%. Only one patient who developed acute closure received a stent. This angiographic oversized balloon angioplasty with IVUS guidance resulted in a larger final MLD without increased rates of significant dissections or ischemic complications. In the Strategy of Intracoronary Ultrasound Guided PTCA and Stenting (SIPS) trial,[278] 269 patients (358 lesions) were randomized to IVUS-guided intervention or angiography-guided intervention. Stenting was performed in about 50% of lesions in both groups. Major adverse cardiac events (MACE) during hospitalization were less with the IVUS-guided group. The reduction of MACE by IVUS guidance was 79%. They concluded that IVUS-guided intervention could reduce acute MACE. The Washington Hospital Center reported acute and late benefits of IVUS-guided balloon angioplasty using balloons sized according to the media-to-media diameter as determined by IVUS.[279] The end point used in this study was achieving a minimum lumen cross sectional area (MLCSA) greater than 70% of the average reference vessel area with no lumen compromising dissections. Crossover to stenting was needed in 61% of lesions. They showed that IVUS-guided PTCA achieved a "stent-like" lumen in 39% of patients with no abrupt closure episodes. An acceptable target lesion revascularization rate of 17% was reported. Recently, from a similar analysis for LAD lesions, they reported that 43% of lesions did not need stent implantation, and the target lesion revascularization was only 8.0% at 9 months.[280]

Clinical examples of "provisional stenting" are shown in Figs 37 and 38. Figure 37 shows how IVUS guidance revealed that placement of a stent was not necessary. Figure 38 shows how IVUS helped determine which of several lesions needed a stent despite the angiographic result.

Recently, a strategy of provisional stenting with a delayed angiogram at 30 minutes was suggested as an alternative to IVUS guidance.[281] It remains to be clarified if this strategy provides comparative results to those with IVUS guidance.

These preliminary results support the utility of IVUS-guided provisional stenting and have provided the impetus to extend this approach to the treatment of long lesions. This technique is called *spot stenting* and is described in the following paragraph.

IVUS-Guided Spot Stenting

To address the high restenosis rate associated with stenting long lesions or lesions in small vessels, the concept of spot stenting has evolved. The treatment of long lesions and lesions in small vessels has historically yielded poor immediate and long-term results when approached with traditional balloon angioplasty.[236,282-285] Angiographic restenosis rates for these lesions have ranged from 41% to 55%. In the STRESS subanalysis, smaller vessels treated with PTCA had a restenosis rate of 53%. Treatment of focal lesions with coronary stenting in vessels greater than 3.0 mm reduces restenosis when compared with balloon angioplasty.[61,62,274] However, stenosis length, length of the stent deployed, and small reference diameter were reported to be independent predictors of restenosis within stents.[168,276] Spot stenting is an attempt to use IVUS guidance to treat long lesions by taking advantage of the benefits of balloon angioplasty and reserving the use of stents to treat residual focal stenoses.

Based on the provisional stenting data, it was hypothesized that the restenosis rate for long lesions and diffuse disease could be reduced if IVUS-guided PTCA would be used as the primary modality while reserving coronary stents to those segments of a lesion where lumen dimensions did not meet prespecified IVUS criteria. Instead of traditional stenting where a lesion is covered from a proximal normal segment to a distal normal segment, the concept behind the spot stenting approach is to avoid stenting long segments even if small dissections are left behind, provided that the dilated sections have an adequate lumen CSA by IVUS. Preliminary data to support the use of this approach have been provided.[286] In that

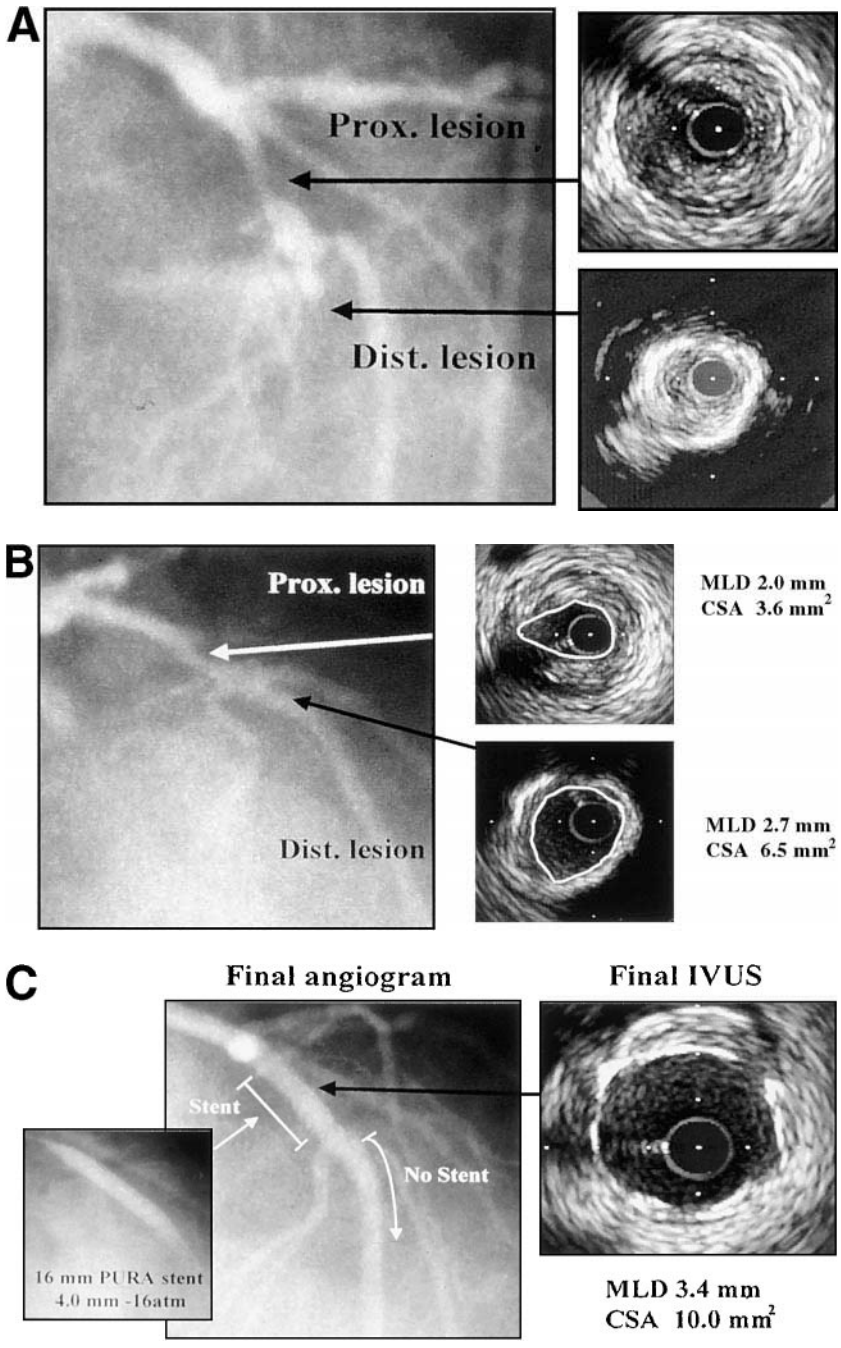

Fig 38. This proximal LAD has a significant stenosis followed by complete occlusion after the bifurcation of the diagonal and first septal perforator. The lesion was dilated with a 30-mm long, 3.0-mm diameter balloon at 14 atm. The corresponding IVUS images following recanalization and balloon dilatation at the proximal and distal lesions are shown to the right of the preintervention angiogram (A). Proximally the vessel was about 4 mm in diameter media to media. The lumen size was still inadequate at a 2-mm diameter following the 3-mm balloon dilatation. The distal lesion was intensely calcified, although the majority of the calcium was positioned toward the base or mid portion of the plaque. Instead of using rotational atherectomy, a larger balloon was chosen. A 20-mm long by 4-mm diameter balloon was expanded at 14 atm. The subsequent angiogram (B) showed an adequate angioplasty result in both the proximal and distal segments. However, the IVUS exam revealed an unexpected disparity. The distal lesion, despite being heavily calcified, was expanded adequately by the balloon dilatation, whereas the fibrotic proximal lesion showed more elastic recoil with a minimum lumen diameter of only 2 mm. Based on these observations, a 16-mm long PURA stent was placed in the proximal, but not the distal lesion, and inflated with a 4-mm balloon at 16 atm. The final angiogram is provided (C). The final IVUS study showed that the proximal lesion was now 3.4 mm in diameter with a CSA of 10.0 mm^2.

report, long lesions (greater than 15 mm) or lesions located in small vessels (less than 3.0 mm) were approached with primary PTCA using a balloon-to-vessel ratio of 1:1. The vessel size was defined as the reference media-to-media diameter measured by a preintervention IVUS study. IVUS criteria for success were defined as achievement of a lumen CSA greater than 50% of the vessel CSA at the lesion site or a minimum lumen CSA greater than 5.5 mm^2. If the IVUS criteria were met in all segments of the lesion after initial balloon dilatation, the procedure was considered complete. If the IVUS criteria were not met, the operator would consider using a larger balloon or higher pressure if deemed possible. If this were not possible, a stent was implanted focally only in

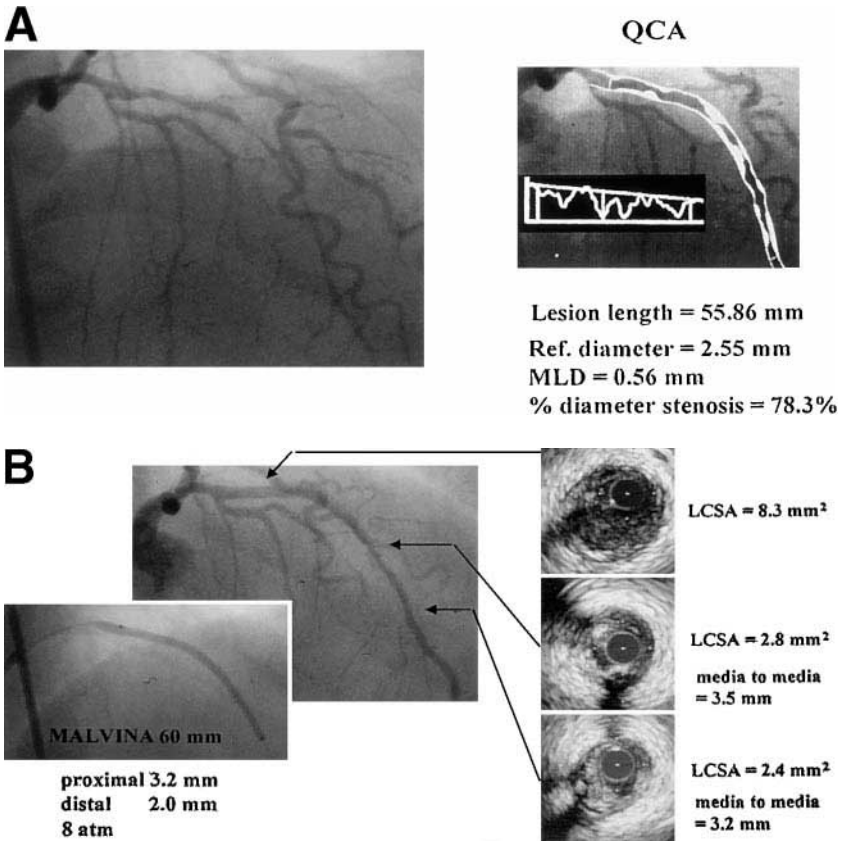

Fig 39. This case represents another diffusely diseased LAD where not many treatment options are available, which would benefit from the spot stenting approach (A). This lesion was 56 mm in length, and the reference lumen diameter measured 2.55 mm by QCA. QCA measurements in sizing vessels has been shown to be less accurate than IVUS measurements, especially in small vessels and vessels with diffuse disease. A long tapering balloon was used for predilatation that was 60 mm in length and tapered from 3.2 mm in diameter in the proximal portion to 2.0 mm in the distal portion. After the first inflation to 8 atm, IVUS was performed and showed that the lesion in the mid to distal segment of the artery was fibrocalcific in nature and that the media-to-media diameter in the distal lesion was 3.2 mm (B). Based on these observations, a 3.0-mm cutting balloon was applied only in the mid to distal segment of the lesion where the lumen CSA did not meet our minimal criteria.

the segment or segments of the lesion where the IVUS criteria had not been achieved, taking care to use the shortest stent length necessary to obtain an optimal result. Fifty percent of all treated lesions achieved the IVUS criteria with PTCA alone, whereas the other 50% required the placement of a focal stent. The average stent length used in the lesions that did not meet IVUS criteria by PTCA alone was 19.0 $\pm$ 12 mm. This was actually shorter than the average lesion length (20.7 $\pm$ 12 mm). In contrast, in previous studies it was common that stent length significantly exceeded lesion length, such as in the STRESS, BENESTENT I, and BENESTENT II Trials.[61,62,165] This is an important concept because evidence shows that the length of deployed stent is a major contributing factor to restenosis.[168,276] Overall results for this approach in 109 lesions in 71 patients were reported as follows: a MACE occurred in 25%, the angiographic restenosis rate was 18%, and the target lesion revascularization rate was 15%. This approach of IVUS-guided PTCA with spot stenting allowed safe treatment of long lesions and lesions in small vessels and achieved 6-month MACE and restenosis rates that appear to be lower compared with historic controls in these difficult lesion subsets. In addition to maximizing the acute gain, IVUS plays an essential role for this approach in terms of procedural safety. Historically, balloon angioplasty performed with angiographically oversized balloons without IVUS guidance was reported to be associated with a poor outcome.[66,67] Furthermore, placing a stent without fully covering the lesion has been viewed as dangerous because of the theoretical risk of acute or subacute stent thrombosis due to the potential flow disturbance and lesion reactivity. However, when IVUS is used to guide the intervention, any flow limiting segments or dissections can be more accurately assessed and a more educated decision made as to whether this segment can be left untreated.[287] The incidence of acute and subacute thrombosis in the spot stenting trial was as low as any of the major stent trials where less complex lesions were treated.

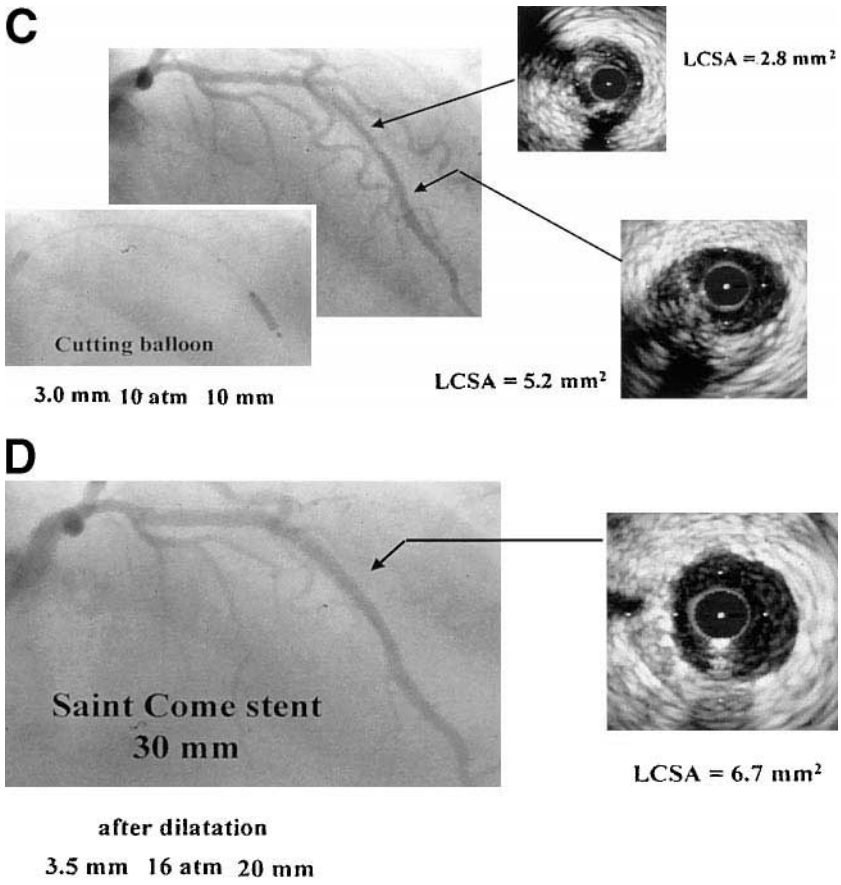

Fig 39. (Cont'd) The cutting balloon was effective in achieving the minimal criteria in the more distal segment where the lumen by IVUS now measured greater than 50% of the reference vessel area (C). In the mid portion, the luminal result was still unsatisfactory, with a CSA of 2.8 mm², so a stent was deployed only in the mid segment. This stent was 30 mm in length and was postdilated with a 3.5-mm balloon to 16 atm. The final angiogram shows an excellent result, and the IVUS measurement shows the new CSA in the mid portion to be 6.7 mm² (D).

An example of the spot stenting strategy is shown in Fig 39. An example of spot stenting with a 6-month follow-up study is shown in Fig 40.

Treatment of In-Stent Restenosis

With the explosion in the use of intracoronary stents in recent years, the problem of in-stent restenosis has been receiving increased attention. Ideally, to minimize further recurrences, the management of in-stent restenosis should not only address the new tissue growth but also the predilection for the exuberant proliferative response present in such lesions. Balloon angioplasty is safe, relatively inexpensive, and appears to be reasonably effective for focal in-stent restenosis.[288,289] Debulking devices such as DCA,[95] rotational atherectomy,[290,291] laser atherectomy,[292,293] and other tools such as the cutting balloon,[294,295] also appear to be safe and possibly somewhat more effective than balloon angioplasty. However, they have limited power to reduce rerestenosis so that optimal strategies need to be defined. Additional stents might be effective,[296-301] especially in combination with the use of antiproliferative strategies such as radiation therapy.[302] Additional stents should be used to cover important dissections occurring in the therapy of in-stent restenosis[303] and also may be effective in reducing the problem of "instant" restenosis,[304] ie, recoil of fibrous tissue through the stent struts back into the lumen.

How does IVUS help during treatment of this lesion subset? IVUS may be helpful by detecting "pseudo–in-stent restenosis"[305] and "instant" restenosis[304] better than angiography.

Pseudo–In-Stent Restenosis

After the implantation of a rigid slotted tube stent, neointimal proliferation occurs in response to the barotrauma applied to the vessel wall as

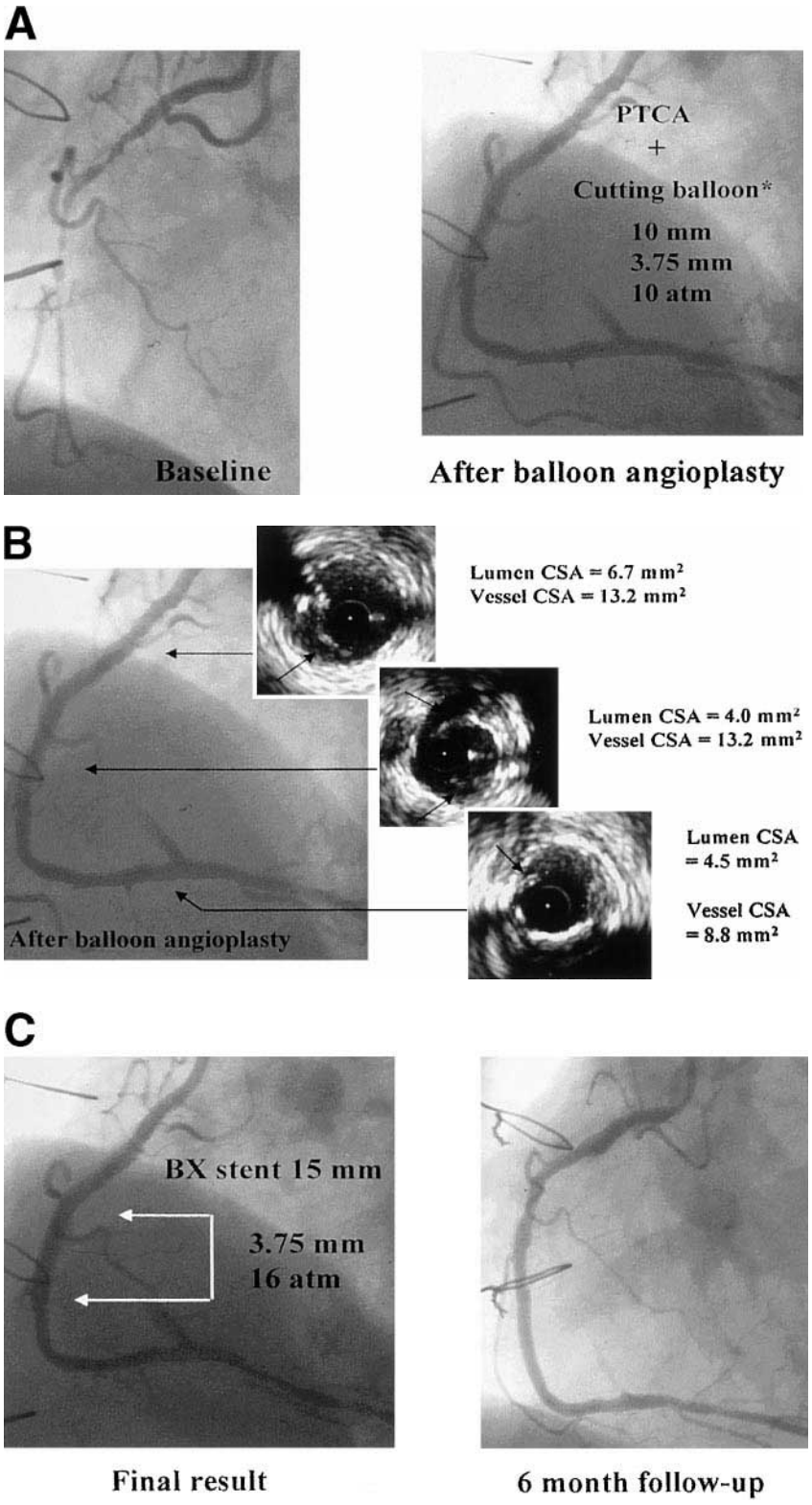

Fig 40. The initial approach to this subtotal occlusion in the right coronary artery was to use balloon angioplasty followed by a cutting balloon (A). This produced a good angiographic result. IVUS interrogation showed that there was an inadequate CSA in the mid portion (CSA less than 5.5 mm² and less than 50% of the reference vessel area at the lesion site) even though there was an optimal angiographic result (B). The lumen in the distal portion met minimal criteria of being greater than 50% of the vessel area. The final step was to place a 15-mm BX stent only in the specific site with the inadequate result in the mid portion. The 6-month angiographic follow-up showed an excellent long-term result with minimal recoil and little intimal hyperplasia (C).

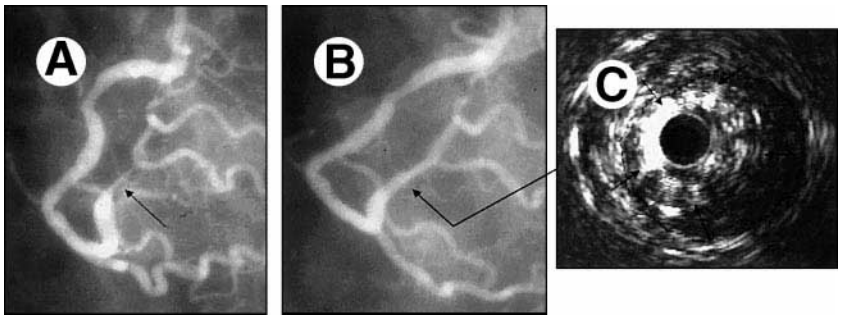

Fig 41. Angiogram and IVUS image of inadequate stent expansion, not seen angiographically. (A) Baseline stenosis in the posterolateral branch of a RCA. (B) Angiogram after a Palmaz-Schatz stent is implanted. An acceptable result is seen. (C) IVUS image showing unsuccessful stent expansion at this site. The arrows point out the struts of the stent. Because the stent is porous, the contrast streams outside the stent struts giving the illusion by angiography of a well-expanded stent. If this is not recognized and recoil of the artery on the stent occurs, the angiographic appearance would be indistinguishable from in-stent intimal hyperplasia, but this would actually be an example of stent pseudo-restenosis.

well as the persistent irritation of the foreign body.[254,306] Pseudo–in-stent restenosis is defined as a stenotic lesion within the stent at follow-up that is caused by inadequate stent expansion during the initial use rather than intimal hyperplasia (Fig 41). Alternatively, a stent may be compressed by external vessel recoil[305] (Fig 42). If the stent is not radio-opaque, the cause of the angio-

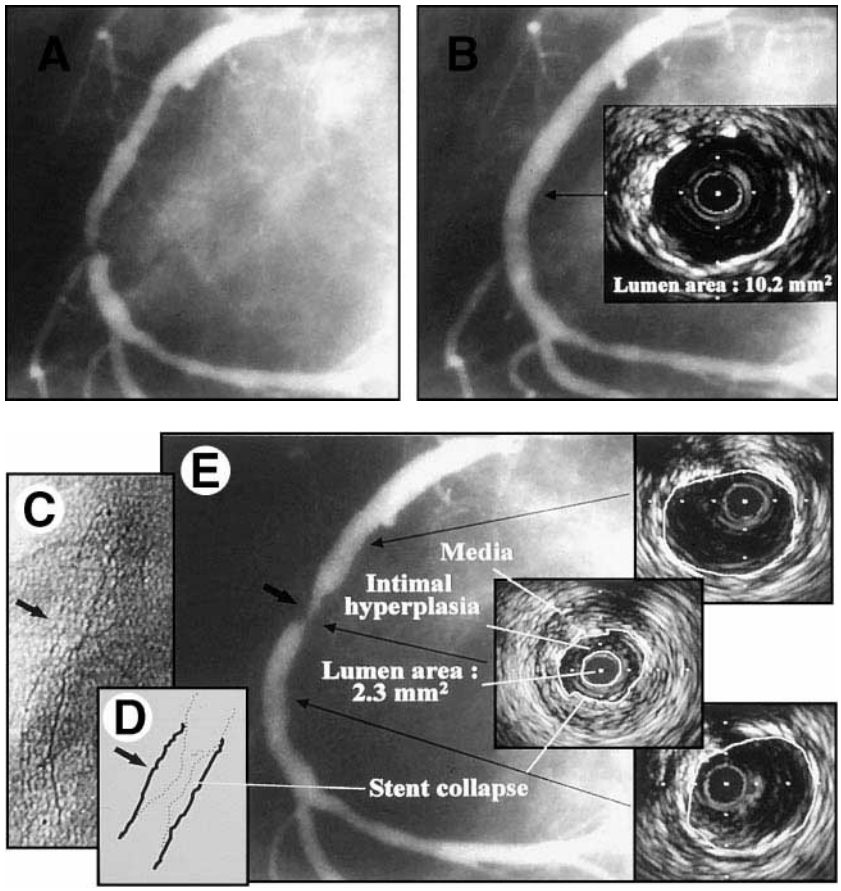

Fig 42. A stenosis in the RCA treated with a long stent. (A) Baseline. (B) After stenting with an acceptable angiographic and IVUS image. (C) At 6-month follow-up. Fluoroscopic outline of the stent showing partial stent collapse (arrow). (D) A cartoon outlining the stent as seen in (C). (E) Angiogram showing stent restenosis at the site of the partial stent collapse (short arrow). IVUS images are seen at the site of stent restenosis showing a smaller intrastent area than seen at the time of stent implantation, as well as some intimal proliferation. IVUS images of the stent (long arrows) proximal and distal to the site of restenosis reveals no evidence of stent collapse or intimal proliferation.

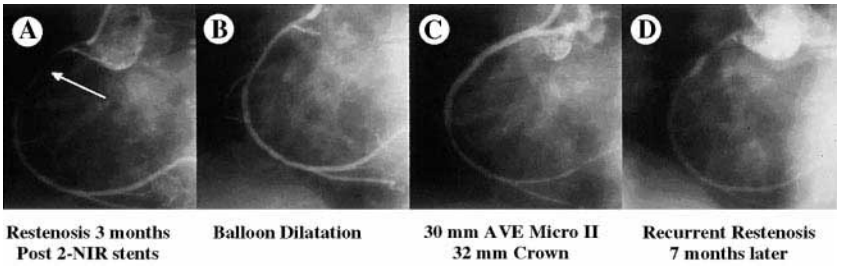

Fig 43. Treatment of in-stent restenosis with additional stent placement. (A) In-stent restenosis in an ostial/proximal RCA. Two 16-mm NIR stents had been placed 3 months previously. Arrow points to lesion. (B) After treatment with balloon angioplasty of the in-stent restenotic lesion. (C) After placement of a 30-mm long Microstent II and a 32-mm Crown stent, an improved angiographic appearance compared with after balloon angioplasty alone. (D) Recurrent in-stent restenosis 7 months later. Despite improving the initial angiographic appearance with the placement of additional stents, aggressive recurrent restenosis has occurred.

graphic restenosis may not be appreciated unless IVUS is performed.

The "Instant" In-Stent Restenosis

The concept of "instant" in-stent restenosis, termed by the Washington Hospital Center group, was derived from the observation that, although the neo-intimal tissue decreased immediately after balloon angioplasty (or ablative therapy) for in-stent restenosis, it might recur after only a few minutes by prolapse of the extruded tissue.[304] Placement of an additional stent prevents this tissue from reentering the lumen.[299] IVUS should

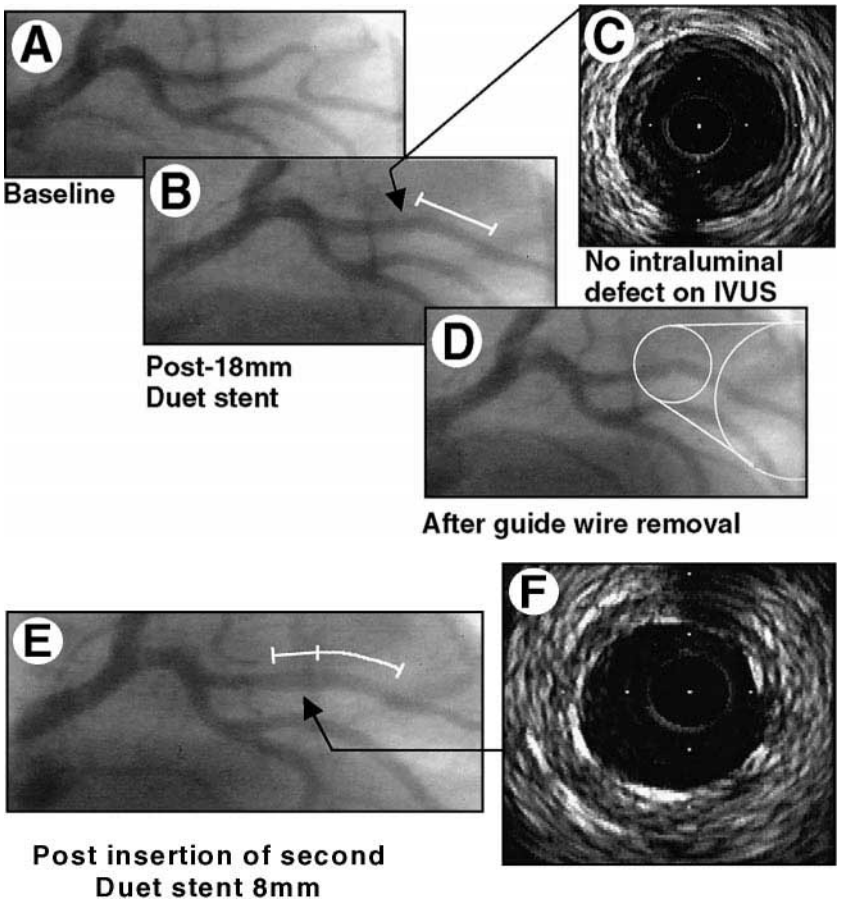

Fig 44. After implanting an 18-mm MultiLink Duet stent to treat a tortuous obtuse marginal artery, examination with angiography (B) and IVUS imaging (C) showed no intraluminal problem. However, after removing the catheter and guide wire, a linear lucency was noticed at the proximal stent edge (D). It was speculated that IVUS catheter and guide wire straightened the sharp bend created by the intersection of the tortuous artery and the edge of the stent, and thus temporarily effaced the lumen encroachment by a fold in the artery. Based solely on the angiographic appearance, an 8-mm long Duet stent was implanted to buttress the proximal entrance to the first stent (E, F).

detect this phenomenon with greater sensitivity than angiography and help determine whether additional stenting is necessary. Despite these favorable results on acute luminal results, the subsequent event rate has been high after repeat stent implantation to treat in-stent restenosis (Fig 43).

Limitations of IVUS

Despite the many benefits to using IVUS as an adjunct to coronary angiography, there clearly are several limitations of this method. First, with a simple injection of contrast, angiography can delineate a coronary artery with its branches, whereas IVUS imaging can examine only one artery at a time. Additional passes are needed to assess branch vessels. Second, IVUS can examine only the portion of the artery that accommodates the diameter of the IVUS catheter, which is more than 2.5 F at the present time. Third, IVUS images may be blemished by artifacts that interfere with the correct interpretation of the image. This includes ringdown artifact, guide wire artifact, acoustic shadowing, position-related artifacts, movement artifacts, and nonuniform rotational distortion.[307] Fourth, some IVUS systems have an acoustic dead zone around the catheter on the image, which may limit the evaluation of lesions with very tight stenosis.[308] Fifth, IVUS cannot evaluate angulation of the arterial segment because the device provides an instantaneous cross-sectional view along the length of the artery. Three-dimensional reconstructions stack up these slices into a straight line. In addition, the IVUS catheter may mechanically straighten a bend in the artery. This occasionally produces a false negative ultrasound result. An interesting case example of this is shown in Fig 44.

Summary

This review has attempted to show the areas where IVUS may provide additional information that is not available by angiography alone. Not only does the use of IVUS facilitate the performance of interventional procedures, especially in complex lesion subsets, the use of IVUS may lead to lower complication rates as well as improved restenosis data and target lesion revascularization. These advantages of IVUS have led to a cost-benefit analysis that suggests that the use of IVUS guidance is cost-effective.[169,278,309-311]

References

1. Rensing BJ, Hermans WR, Vos J, et al: Luminal narrowing after percutaneous transluminal coronary angioplasty. A study of clinical, procedural, and lesional factors related to long-term angiographic outcome. Coronary Artery Restenosis Prevention on Repeated Thromboxane Antagonism (CARPORT) Study Group. Circulation 88:975-985, 1993
2. Keane D, Melkert R, Herrman JP, et al: Quantitative coronary angiography endpoints: A valid surrogacy for clinical events, in de Feyter PJ, Di Mario C, Serruys PW (eds): Quantitative Coronary Imaging. Rotterdam, The Netherlands, Barjesteh, Meeuwes & Co, 1995, pp 57-88
3. Yock PG, Johnson EL, Linker DT: Intravascular ultrasound: Development and clinical potential. Am J Card Imaging 2:185-193, 1988
4. Ryan TJ, Faxon DP, Gunnar RM, et al: Guidelines for percutaneous transluminal coronary angioplasty. A report of the American College of Cardiology/American Heart Association Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures (Subcommittee on Percutaneous Transluminal Coronary Angioplasty). J Am Coll Cardiol 12:529-545, 1988
5. Nissen SE, Gurley JC, Grines CL, et al: Intravascular ultrasound assessment of lumen size and wall morphology in normal subjects and patients with coronary artery disease. Circulation 84:1087-1099, 1991
6. Arnett EN, Isner JM, Redwood DR, et al: Coronary artery narrowing in coronary heart disease: Comparison of cineangiographic and necropsy findings. Ann Intern Med 91:350-356, 1979
7. Vlodaver Z, Frech R, Van Tassel RA, Edwards JE: Correlation of the antemortem coronary arteriogram and the postmortem specimen. Circulation 47:162-169, 1973
8. Vlodaver Z, Edwards JE: Pathology of coronary atherosclerosis. Prog Cardiovasc Dis 14:256-274, 1971
9. Waller BF, Roberts WC: Amount of narrowing by atherosclerotic plaque in 44 nonbypassed and 52 bypassed major epicardial coronary arteries in 32 necropsy patients who died within 1 month of aorto-coronary bypass grafting. Am J Cardiol 46:956-962, 1980
10. Waller BF: Anatomy, histology, and pathology of the major epicardial coronary arteries relevant to echocardiographic imaging techniques. J Am Soc Echocardiogr 2:232-252, 1989
11. Waller BF, Pinkerton CA, Slack JD: Intravascular ultrasound: A histological study of vessels during life. The new 'gold standard' for vascular imaging. Circulation 85:2305-2310, 1992
12. Warnes CA, Roberts WC: Comparison at necropsy by age group of amount and distribution of narrowing

by atherosclerotic plaque in 2995 five-mm long segments of 240 major coronary arteries in 60 men aged 31 to 70 years with sudden coronary death. Am Heart J 108:431-435, 1984

13. Glagov S, Weisenberg E, Zarins CK, et al: Compensatory enlargement of human atherosclerotic coronary arteries. N Engl J Med 316:1371-1375, 1987

14. Nissen SE, Grines CL, Gurley JC, et al: Application of a new phased-array ultrasound imaging catheter in the assessment of vascular dimensions: In vivo comparison to cineangiography. Circulation 81:660-666, 1990

15. Nakamura S, Mahon DJ, Maheswaran B, et al: An explanation for discrepancy between angiographic and intravascular ultrasound measurements after percutaneous transluminal coronary angioplasty. J Am Coll Cardiol 25:633-639, 1995

16. Ehrlich S, Honye J, Mahon D, et al: Unrecognized stenosis by angiography documented by intravascular ultrasound imaging. Cathet Cardiovasc Diagn 23:198-201, 1991

17. Hausmann D, Lundkvist AJ, Friedrich G, et al: Lumen and plaque shape in atherosclerotic coronary arteries assessed by in vivo intracoronary ultrasound. Am J Cardiol 74:857-863, 1994

18. Hausmann D, Lundkvist AJ, Friedrich GJ, et al: Intracoronary ultrasound imaging: Intraobserver and interobserver variability of morphometric measurements. Am Heart J 128:674-680, 1994

19. Waller BF: The eccentric coronary atherosclerotic plaque: Morphologic observations and clinical relevance. Clin Cardiol 12:14-20, 1989

20. Potkin BN, Bartorelli AL, Gessert JM, et al: Coronary artery imaging with intravascular high-frequency ultrasound. Circulation 81:1575-1585, 1990

21. Mintz GS, Popma JJ, Pichard AD, et al: Limitations of angiography in the assessment of plaque distribution in coronary artery disease: A systematic study of target lesion eccentricity in 1446 lesions. Circulation 93:924-931, 1996

22. Linker DT, Kleven A, Groenningsaether A, et al: Tissue characterization with intra-arterial ultrasound: Special promise and problem. Int J Card Imaging 6:255-263, 1991

23. Rasheed Q, Dhawale PJ, Anderson J, Hodgson JM: Intracoronary ultrasound-defined plaque composition: Computer-aided plaque characterization and correlation with histologic samples obtained during directional coronary atherectomy. Am Heart J 129: 631-637, 1995

24. Keren G, Leon MB: Characterization of atherosclerotic lesions by intravascular ultrasound: Possible role in unstable coronary syndromes and in interventional therapeutic procedures. Am J Cardiol 68:85B-91B, 1991

25. Tobis JM, Mallery J, Mahon D, et al: Intravascular ultrasound imaging of human coronary arteries in vivo. Analysis of tissue characterizations with comparison to in vitro histological specimens. Circulation 83:913-926, 1991

26. Linker DT, Yock PG, Groenningsaether A, et al: Analysis of backscattered ultrasound from normal and diseased arterial wall. Int J Card Imaging 4:177-185, 1989

27. Fitzgerald PJ, Ports TA, Yock PG: Contribution of localized calcium deposits to dissection after angioplasty: An observational study using intravascular ultrasound. Circulation 86:64-70, 1992

28. Friedrich GJ, Moes NY, Muhlberger VA, et al: Detection of intralesional calcium by intracoronary ultrasound depends on the histologic pattern. Am Heart J 128:435-441, 1994

29. Hiro T, Leung CY, Russo RJ, et al: Variability in tissue characterization of atherosclerotic plaque by intravascular ultrasound: A comparison of four intravascular ultrasound systems. Am J Card Imaging 10:209-218, 1996

30. Zamorano J, Erbel R, Ge J, et al: Spontaneous plaque rupture visualized by intravascular ultrasound. Eur Heart J 15:131-133, 1994

31. Park JB, Tobis JM: Spontaneous plaque rupture and thrombus formation in the left main coronary artery documented by intravascular ultrasound. Cathet Cardiovasc Diagn 40:358-360, 1996

32. Davies MJ, Thomas AC: Plaque fissuring—The cause of acute myocardial infarction, sudden ischaemic death, and crescendo angina. Br Heart J 53:363-373, 1985

33. Kimura BJ, Bhargava V, DeMaria AN: Value and limitations of intravascular ultrasound imaging in characterizing coronary atherosclerotic plaque. Am Heart J 130:386-396, 1995

34. Moore MP, Spencer T, Salter DM, et al: Characterisation of coronary atherosclerotic morphology by spectral analysis of radiofrequency signal: In vitro intravascular ultrasound study with histological and radiological validation. Heart 79:459-467, 1998

35. Mintz GS, Douek P, Pichard AD, et al: Target lesion calcification in coronary artery disease: An intravascular ultrasound study. J Am Coll Cardiol 20:1149-1155, 1992

36. Rosenfield K, Losordo DW, Ramaswamy K, et al: Three-dimensional reconstruction of human coronary and peripheral arteries from images recorded during two-dimensional intravascular ultrasound examination. Circulation 84:1938-1956, 1991

37. Nissen SE, Gurley JC, Booth DC, DeMaria AN: Intravascular ultrasound of the coronary arteries: Current applications and future directions. Am J Cardiol 69:18H-29H, 1992

38. Mintz GS, Potkin BN, Cooke R, et al: Intravascular ultrasound imaging in a patient with unstable angina. Am Heart J 123:1692-1694, 1992

39. Fitzpatrick LA, Severson A, Edwards WD, Ingram RT: Diffuse calcification in human coronary arteries. Association of osteopontin with atherosclerosis. J Clin Invest 94:1597-1604, 1994

40. Block PC, Myler RK, Stertzer S, Fallon JT: Morphology after transluminal angioplasty in human beings. N Engl J Med 305:382-385, 1981

41. Block PC: Mechanism of transluminal angioplasty. Am J Cardiol 53:69C-71C, 1984

42. Block PC, Baughman KL, Pasternak RC, Fallon JT: Transluminal angioplasty: Correlation of morphologic and angiographic findings in an experimental model. Circulation 61:778-785, 1980

43. Farb A, Virmani R, Atkinson JB, Kolodgie FD: Plaque morphology and pathologic changes in arteries from patients dying after coronary balloon angioplasty. J Am Coll Cardiol 16:1421-1429, 1990

44. Soward AL, Essed CE, Serruys PW: Coronary arterial findings after accidental death immediately after successful percutaneous transluminal coronary angioplasty. Am J Cardiol 56:794-795, 1985

45. Mizuno K, Kurita A, Imazeki N: Pathological findings after percutaneous transluminal coronary angioplasty. Br Heart J 52:588-590, 1984

46. Lyon RT, Zarins CK, Lu CT, et al: Vessel, plaque, and lumen morphology after transluminal balloon angioplasty. Quantitative study in distended human arteries. Arteriosclerosis 7:306-314, 1987

47. Waller BF: Morphologic correlates of coronary angiographic patterns at the site of percutaneous transluminal coronary angioplasty. Clin Cardiol 11:817-822, 1988

48. Waller BF, Gorfinkel HJ, Rogers FJ, et al: Early and late morphologic changes in major epicardial coronary arteries after percutaneous transluminal coronary angioplasty. Am J Cardiol 53:42C-47C, 1984

49. Waller BF: Pathology of transluminal balloon angioplasty used in the treatment of coronary heart disease. Hum Pathol 18:476-484, 1987

50. Tobis JM, Mallery JA, Gessert J, et al: Intravascular ultrasound cross-sectional arterial imaging before and after balloon angioplasty in vitro. Circulation 80:873-882, 1989

51. Honye J, Mahon DJ, Jain A, et al: Morphological effects of coronary balloon angioplasty in vivo assessed by intravascular ultrasound imaging. Circulation 85:1012-1025, 1992

52. Potkin BN, Keren G, Mintz GS, et al: Arterial responses to balloon coronary angioplasty: An intravascular ultrasound study. J Am Coll Cardiol 20:942-951, 1992

53. Hodgson JM, Reddy KG, Suneja R, et al: Intracoronary ultrasound imaging: Correlation of plaque morphology with angiography, clinical syndrome and procedural results in patients undergoing coronary angioplasty. J Am Coll Cardiol 21:35-44, 1993

54. Fitzgerald PJ, Yock PG: Mechanisms and outcomes of angioplasty assessed by intravascular ultrasound imaging. J Clin Ultrasound 21:579-588, 1993

55. Di Mario C, Gorge G, Peters R, et al: Clinical application and image interpretation in intracoronary ultrasound. Study Group on Intracoronary Imaging of the Working Group of Coronary Circulation and of the Subgroup on Intravascular Ultrasound of the Working Group of Echocardiography of the European Society of Cardiology. Eur Heart J 19:207-229, 1998

56. Kobayashi N, De Gregorio J, Adamian M, et al: New approaches to evaluate coronary dissections post coronary intervention: All dissections are not malignant. J Am Coll Cardiol 33:71A, 1999 (abstr, suppl A)

57. Gerber TC, Erbel R, Gorge G, et al: Classification of morphologic effects of percutaneous transluminal coronary angioplasty assessed by intravascular ultrasound. Am J Cardiol 70:1546-1554, 1992

58. Ozaki Y, Violaris AG, Kobayashi T, et al: Comparison of coronary luminal quantification obtained from intracoronary ultrasound and both geometric and videodensitometric quantitative angiography before and after balloon angioplasty and directional atherectomy. Circulation 96:491-499, 1997

59. Kuntz RE, Gibson CM, Nobuyoshi M, Baim DS: Generalized model of restenosis after conventional balloon angioplasty, stenting and directional atherectomy. J Am Coll Cardiol 21:15-25, 1993

60. Topol EJ, Leya F, Pinkerton CA, et al: A comparison of directional atherectomy with coronary angioplasty in patients with coronary artery disease. The CAVEAT Study Group. N Engl J Med 329:221-227, 1993

61. Serruys PW, de Jaegere P, Kiemeneij F, et al: A comparison of balloon-expandable-stent implantation with balloon angioplasty in patients with coronary artery disease. Benestent Study Group. N Engl J Med 331:489-495, 1994

62. Fischman DL, Leon MB, Baim DS, et al: A randomized comparison of coronary-stent placement and balloon angioplasty in the treatment of coronary artery disease. Stent Restenosis Study Investigators. N Engl J Med 331:496-501, 1994

63. Rensing BJ, Hermans WR, Deckers JW, et al: Lumen narrowing after percutaneous transluminal coronary balloon angioplasty follows a near gaussian distribution: A quantitative angiographic study in 1,445 successfully dilated lesions. J Am Coll Cardiol 19:939-945, 1992

64. Beatt KJ, Serruys PW, Luijten HE, et al: Restenosis after coronary angioplasty: The paradox of increased lumen diameter and restenosis. J Am Coll Cardiol 19:258-266, 1992

65. Pepine CJ, Hirshfeld JW, Macdonald RG, et al: A controlled trial of corticosteroids to prevent restenosis after coronary angioplasty. M-HEART Group. Circulation 81:1753-1761, 1990

66. Roubin GS, Douglas JSJ, King SB, et al: Influence of balloon size on initial success, acute complications, and restenosis after percutaneous transluminal coronary angioplasty. A prospective randomized study. Circulation 78:557-565, 1988

67. Nichols AB, Smith R, Berke AD, et al: Importance of balloon size in coronary angioplasty. J Am Coll Cardiol 13:1094-1100, 1989

68. Gruntzig A: Transluminal dilatation of coronary-artery stenosis. Lancet 1:263, 1978

69. Gruntzig AR, Senning A, Siegenthaler WE: Nonoperative dilatation of coronary-artery stenosis: Percutaneous transluminal coronary angioplasty. N Engl J Med 301:61-68, 1979

70. Marcus ML, Armstrong ML, Heistad DD, et al: Comparison of three methods of evaluating coronary

obstructive lesions: Postmortem arteriography, pathologic examination and measurement of regional myocardium perfusion during maximal vasodilation. Am J Cardiol 49:1699-1706, 1982

71. Mintz GS, Painter JA, Pichard AD, et al: Atherosclerosis in angiographically "normal" coronary artery reference segments: An intravascular ultrasound study with clinical correlations. J Am Coll Cardiol 25:1479-1485, 1995

72. Losordo DW, Rosenfield K, Kaufman J, et al: Focal compensatory enlargement of human arteries in response to progressive atherosclerosis. In vivo documentation using intravascular ultrasound. Circulation 89:2570-2577, 1994

73. Davidson CJ, Sheikh KH, Kisslo KB, et al: Intracoronary ultrasound evaluation of interventional technologies. Am J Cardiol 68:1305-1309, 1991

74. Stone GW, Hodgson JM, St Goar FG, et al: Improved procedural results of coronary angioplasty with intravascular ultrasound-guided balloon sizing: The CLOUT Pilot Trial. Clinical Outcomes With Ultrasound Trial (CLOUT) Investigators. Circulation 95: 2044-2052, 1997

75. Holmes DR, Vliestra RE, Smith HC, et al: Restenosis after percutaneous transluminal coronary angioplasty (PTCA): A report from the PTCA registry of the National Heart, Lung, and Blood Institute. Am J Cardiol 53:77C-81C, 1984

76. Detre K, Holubkov R, Kelsey S, et al: Percutaneous transluminal coronary angioplasty in 1985-1986 and 1977-1981. The National Heart, Lung, and Blood Institute Registry. N Engl J Med 318:265-270, 1988

77. Serruys PW, Luijten HE, Beatt KJ, et al: Incidence of restenosis after successful coronary angioplasty: A time-related phenomenon. A quantitative angiographic study in 342 consecutive patients at 1, 2, 3, and 4 months. Circulation 77:361-371, 1988

78. Nobuyoshi M, Kimura T, Nosaka H, et al: Restenosis after successful percutaneous transluminal coronary angioplasty: Serial angiographic follow-up of 229 patients. J Am Coll Cardiol 12:616-623, 1988

79. Reidy MA, Finferle J, Lindner V: Factors controlling the development of arterial lesions after injury. Circulation 86:III-43-III-46, 1992 (abstr, suppl III)

80. Schwartz RS, Huber KC, Murphy JG, et al: Restenosis and the proportional neointimal response to coronary artery injury: Results in a porcine model. J Am Coll Cardiol 19:267-274, 1992

81. Schwartz RS, Murphy JG, Edwards WD, et al: Restenosis after balloon angioplasty. A practical proliferative model in porcine coronary arteries. Circulation 82:2190-2200, 1990

82. Steele PM, Chesebro JH, Stanson AW, et al: Balloon angioplasty. Natural history of the pathophysiological response to injury in a pig model. Circ Res 57:105-112, 1985

83. Austin GE, Ratliff NB, Hollman J, et al: Intimal proliferation of smooth muscle cells as an explanation for recurrent coronary artery stenosis after percutaneous transluminal coronary angioplasty. J Am Coll Cardiol 6:369-375, 1985

84. Essed CE, van den Brand M, Becker AE: Transluminal coronary angioplasty and early restenosis. Fibrocellular occlusion after wall laceration. Br Heart J 49:393-396, 1983

85. Bruneval P, Guermonprez JL, Perrier P, et al: Coronary artery restenosis following transluminal coronary angioplasty. Arch Pathol Lab Med 110:1186-1187, 1986

86. Garratt KN, Edwards WD, Vlietstra RE, et al: Coronary morphology after percutaneous directional coronary atherectomy in humans: Autopsy analysis of three patients. J Am Coll Cardiol 16:1432-1436, 1990

87. Ueda M, Becker AE, Fujimoto T: Pathological changes induced by repeated percutaneous transluminal coronary angioplasty. Br Heart J 58:635-643, 1987

88. Gravanis MB, Roubin GS: Histopathologic phenomena at the site of percutaneous transluminal coronary angioplasty: The problem of restenosis. Hum Pathol 20:477-485, 1989

89. Nobuyoshi M, Kimura T, Ohishi H, et al: Restenosis after percutaneous transluminal coronary angioplasty: Pathologic observations in 20 patients. J Am Coll Cardiol 17:433-439, 1991

90. Giraldo AA, Esposo OM, Meis JM: Intimal hyperplasia as a cause of restenosis after percutaneous transluminal coronary angioplasty. Arch Pathol Lab Med 109:173-175, 1985

91. Kohchi K, Takebayashi S, Block PC, et al: Arterial changes after percutaneous transluminal coronary angioplasty: Results at autopsy. J Am Coll Cardiol 10:592-599, 1987

92. Morimoto S, Mizuno Y, Hiramitsu S, et al: Restenosis after percutaneous transluminal coronary angioplasty—A histopathological study using autopsied hearts. Jpn Circ J 54:43-56, 1990

93. Johnson DE, Hinohara T, Selmon MR, et al: Primary peripheral arterial stenoses and restenoses excised by transluminal atherectomy: A histopathologic study. J Am Coll Cardiol 15:419-425, 1990

94. Garratt KN, Edwards WD, Kaufmann UP, et al: Differential histopathology of primary atherosclerotic and restenotic lesions in coronary arteries and saphenous vein bypass grafts: Analysis of tissue obtained from 73 patients by directional atherectomy. J Am Coll Cardiol 17:442-448, 1991

95. Strauss BH, Umans VA, van Suylen RJ, et al: Directional atherectomy for treatment of restenosis within coronary stents: Clinical, angiographic and histologic results. J Am Coll Cardiol 20:1465-1473, 1992

96. Riessen R, Isner JM, Blessing E, et al: Regional differences in the distribution of the proteoglycans biglycan and decorin in the extracellular matrix of atherosclerotic and restenotic human coronary arteries. Am J Pathol 144:962-974, 1994

97. Pickering JG, Weir L, Rosenfield K, et al: Smooth muscle cell outgrowth from human atherosclerotic plaque: Implications for the assessment of lesion biology. J Am Coll Cardiol 20:1430-1439, 1992

98. Bauriedel G, Windstetter U, DeMaio SJJ, et al: Migratory activity of human smooth muscle cells

cultivated from coronary and peripheral primary and restenotic lesions removed by percutaneous atherectomy. Circulation 85:554-564, 1992

99. Pickering JG, Weir L, Jekanowski J, et al: Proliferative activity in peripheral and coronary atherosclerotic plaque among patients undergoing percutaneous revascularization. J Clin Invest 91:1469-1480, 1993

100. Forrester JS, Fishbein M, Helfant R, Fagin J: A paradigm for restenosis based on cell biology: Clues for the development of new preventive therapies. J Am Coll Cardiol 17:758-769, 1991

101. Ellis SG, Muller DW: Arterial injury and the enigma of coronary restenosis. J Am Coll Cardiol 19:275-277, 1992

102. Liu MW, Roubin GS, King SB: Restenosis after coronary angioplasty. Potential biologic determinants and role of intimal hyperplasia. Circulation 79:1374-1387, 1989

103. O'Brien ER, Alpers CE, Stewart DK, et al: Proliferation in primary and restenotic coronary atherectomy tissue. Implications for antiproliferative therapy. Circ Res 73:223-231, 1993

104. Schwartz RS, Holmes DRJ, Topol EJ: The restenosis paradigm revisited: An alternative proposal for cellular mechanisms. J Am Coll Cardiol 20:1284-1293, 1992

105. Lafont A, Guzman LA, Whitlow PL, et al: Restenosis after experimental angioplasty. Intimal, medial, and adventitial changes associated with constrictive remodeling. Circ Res 76:996-1002, 1995

106. Post MJ, Borst C, Kuntz RE: The relative importance of arterial remodeling compared with intimal hyperplasia in lumen renarrowing after balloon angioplasty. A study in the normal rabbit and the hypercholesterolemic Yucatan micropig. Circulation 89:2816-2821, 1994

107. Brott BC, Labinaz M, Culp SC, et al: Vessel remodeling after angioplasty: Comparative anatomic studies. J Am Coll Cardiol 23:138A, 1994 (abstr, suppl)

108. Nunes GL, Sgoutas DS, Sigman SR, et al: Vitamins C and E improve the response to coronary balloon injury in the pig: Effect of vascular remodeling. Circulation 88:1-372, 1993 (abstr, suppl 1)

109. Bier JD, Kakuta T, Currier JW, et al: Arterial remodeling: Importance in primary versus restenotic lesions. J Am Coll Cardiol 23:139A, 1994 (suppl A)

110. Kakuta T, Currier JW, Haudenschild CC, et al: Differences in compensatory vessel enlargement, not intimal formation, account for restenosis after angioplasty in the hypercholesterolemic rabbit model. Circulation 89:2809-2815, 1994

111. Di Mario C, Gil R, Camenzind E, et al: Quantitative assessment with intracoronary ultrasound of the mechanisms of restenosis after percutaneous transluminal coronary angioplasty and directional coronary atherectomy. Am J Cardiol 75:772-777, 1995

112. Mintz GS, Popma JJ, Pichard AD, et al: Arterial remodeling after coronary angioplasty: A serial intravascular ultrasound study. Circulation 94:35-43, 1996

113. Kimura T, Kaburagi S, Tamura T, et al: Remodeling of human coronary arteries undergonig coronary angioplasty or atherectomy. Circulation 96:475-483, 1997

114. De Vrey EA, Mintz GS, von Birgelen C, et al: Serial volumetric (three-dimensional) intravascular ultrasound analysis of restenosis after directional coronary atherectomy. J Am Coll Cardiol 32:1874-1880, 1998

115. Kornowski R, Mintz GS, Kent KM, et al: Increased restenosis in diabetes mellitus after coronary interventions is due to exaggerated intimal hyperplasia: A serial intravascular ultrasound study. Circulation 95: 1366-1369, 1997

116. Adelman AG, Cohen EA, Kimball BP, et al: A comparison of directional atherectomy with balloon angioplasty for lesions of the left anterior descending coronary artery. N Engl J Med 329:228-233, 1993

117. Pavlides GS, Hauser AM, Grines CL, et al: Clinical, hemodynamic, electrocardiographic and mechanical events during nonocclusive, coronary atherectomy and comparison with balloon angioplasty. Am J Cardiol 70:841-845, 1992

118. Matar FA, Mintz GS, Pinnow E, et al: Multivariate predictors of intravascular ultrasound end points after directional coronary atherectomy. J Am Coll Cardiol 25:318-324, 1995

119. Popma JJ, Mintz GS, Satler LF, et al: Clinical and angiographic outcome after directional coronary atherectomy. A qualitative and quantitative analysis using coronary arteriography and intravascular ultrasound. Am J Cardiol 72:55E-64E, 1993

120. Kuntz RE, Hinohara T, Safian RD, et al: Restenosis after directional coronary atherectomy. Effects of luminal diameter and deep wall excision. Circulation 86:1394-1399, 1992

121. Garratt KN, Holmes DRJ, Bell MR, et al: Restenosis after directional coronary atherectomy: Differences between primary atheromatous and restenosis lesions and influence of subintimal tissue resection. J Am Coll Cardiol 16:1665-1671, 1990

122. Baim DS, Hinohara T, Holmes D, et al: Results of directional coronary atherectomy during multicenter preapproval testing. The US Directional Coronary Atherectomy Investigator Group. Am J Cardiol 72:6E-11E, 1993

123. Hinohara T, Robertson GC, Selmon MR, et al: Restenosis after directional coronary atherectomy. J Am Coll Cardiol 20:623-632, 1992

124. Hinohara T, Rowe MH, Robertson GC, et al: Effect of lesion characteristics on outcome of directional coronary atherectomy. J Am Coll Cardiol 17:1112-1120, 1991

125. Johnson DE, Braden L, Simpson JB: Mechanism of directed transluminal atherectomy. Am J Cardiol 65:389-391, 1990

126. Popma JJ, De Cesare NB, Pinkerton CA, et al: Quantitative analysis of factors influencing late lumen loss and restenosis after directional coronary atherectomy. Am J Cardiol 71:552-557, 1993

127. Fishman RF, Kuntz RE, Carrozza JPJ, et al: Long-term results of directional coronary atherectomy:

Predictors of restenosis. J Am Coll Cardiol 20:1101-1110, 1992

128. Nakamura S, Mahon DJ, Leung CY, et al: Intracoronary ultrasound imaging before and after directional coronary atherectomy: In vitro and clinical observations. Am Heart J 129:841-851, 1995

129. Umans VA, Baptista J, Di Mario C, et al: Angiographic, ultrasonic, and angioscopic assessment of the coronary artery wall and lumen area configuration after directional atherectomy: The mechanism revisited. Am Heart J 130:217-227, 1995

130. Hong MK, Wong SC, Mintz GS, et al: A modified directional atherectomy catheter for resection of calcified atherosclerotic plaques. Coron Artery Dis 6:335-339, 1995

131. Kimura BJ, Fitzgerald PJ, Sudhir K, et al: Guidance of directed coronary atherectomy by intracoronary ultrasound imaging. Am Heart J 124:1365-1369, 1992

132. Suneja R, Nair RN, Reddy KG, et al: Mechanisms of angiographically successful directional coronary atherectomy: Evaluation by intracoronary ultrasound and comparison with transluminal coronary angioplasty. Am Heart J 126:507-514, 1993

133. Simonton CA, Leon MB, Baim DS, et al: 'Optimal' directional coronary atherectomy: Final results of the Optimal Atherectomy Restenosis Study (OARS). Circulation 97:332-339, 1998

134. Sumitsuji S, Suzuki T, Hosokawa H, et al: Vessel and plaque change in 3 and 6 months follow-up after aggressive directional coronary atherectomy in Adjunctive Balloon Angioplasty following Coronary Atherectomy Study (ABACAS). Circulation 96:I-408, 1997 (abstr, suppl 1)

135. Herrmann HC, Buchbinder M, Clemen MW, et al: Emergent use of balloon-expandable coronary artery stenting for failed percutaneous transluminal coronary angioplasty. Circulation 86:812-819, 1992

136. Haude M, Erbel R, Straub U, et al: Results of intracoronary stents for management of coronary dissection after balloon angioplasty. Am J Cardiol 67:691-696, 1991

137. Kiemeneij F, Laarman GJ, van der Wieken R, Suwarganda J: Emergency coronary stenting with the Palmaz-Schatz stent for failed transluminal coronary angioplasty: Results of a learning phase. Am Heart J 126:23-31, 1993

138. Fischman DL, Savage MP, Leon MB, et al: Effect of intracoronary stenting on intimal dissection after balloon angioplasty: Results of quantitative and qualitative coronary analysis. J Am Coll Cardiol 18:1445-1451, 1991

139. George BS, Voorhees WD, Roubin GS, et al: Multicenter investigation of coronary stenting to treat acute or threatened closure after percutaneous transluminal coronary angioplasty: Clinical and angiographic outcomes. J Am Coll Cardiol 22:135-143, 1993

140. Roubin GS, Cannon AD, Agrawal SK, et al: Intracoronary stenting for acute and threatened closure complicating percutaneous transluminal coronary angioplasty. Circulation 85:916-927, 1992

141. Strauss BH, Serruys PW, de Scheerder IK, et al: Relative risk analysis of angiographic predictors of restenosis within the coronary Wallstent. Circulation 84:1636-1643, 1991

142. Serruys PW, Strauss BH, Beatt KJ, et al: Angiographic follow-up after placement of a self-expanding coronary-artery stent. N Engl J Med 324:13-17, 1991

143. Schatz RA, Baim DS, Leon M, et al: Clinical experience with the Palmaz-Schatz coronary stent. Initial results of a multicenter study. Circulation 83:148-161, 1991

144. Maiello L, Colombo A, Gianrossi R, et al: Coronary stenting for treatment of acute or threatened closure following dissection after coronary balloon angioplasty. Am Heart J 125:1570-1575, 1993

145. Nath FC, Muller DW, Ellis SG, et al: Thrombosis of a flexible coil coronary stent: Frequency, predictors and clinical outcome. J Am Coll Cardiol 21:622-627, 1993

146. Agrawal SK, Ho DS, Liu MW, et al: Predictors of thrombotic complications after placement of the flexible coil stent. Am J Cardiol 73:1216-1219, 1994

147. Sutton JM, Ellis SG, Roubin GS, et al: Major clinical events after coronary stenting. The multicenter registry of acute and elective Gianturco-Roubin stent placement. The Gianturco-Roubin Intracoronary Stent Investigator Group. Circulation 89:1126-1137, 1994

148. Bilodeau L, Hearn JA, Dean LS, Roubin GS: Prolonged intracoronary urokinase infusion for acute stent thrombosis. Cathet Cardiovasc Diagn 30:141-146, 1993

149. Haude M, Erbel R, Issa H, et al: Subacute thrombotic complications after intracoronary implantation of Palmaz-Schatz stents. Am Heart J 126:15-22, 1993

150. Goldberg SL, Colombo A, Nakamura S, et al: Benefit of intracoronary ultrasound in the deployment of Palmaz-Schatz stents. J Am Coll Cardiol 24:996-1003, 1994

151. Nakamura S, Colombo A, Gaglione A, et al: Intracoronary ultrasound observations during stent implantation. Circulation 89:2026-2034, 1994

152. Uren NG, Schwarzacher SP, Metz JA, et al: Intravascular ultrasound prediction of stent thrombosis: Insights from the POST Registry. J Am Coll Cardiol 29:60A, 1997 (abstr, suppl A)

153. Schatz RA, Goldberg S, Leon M, et al: Clinical experience with the Palmaz-Schatz coronary stent. J Am Coll Cardiol 17:155B-159B, 1991

154. Savage MP, Fischman DL, Schatz RA, et al: Long-term angiographic and clinical outcome after implantation of a balloon-expandable stent in the native coronary circulation. Palmaz-Schatz Stent Study Group. J Am Coll Cardiol 24:1207-1212, 1994

155. Cohen DJ, Krumholz HM, Sukin CA, et al: In-hospital and one-year economic outcomes after coronary stenting or balloon angioplasty. Results from a randomized clinical trial. Stent Restenosis Study Investigators. Circulation 92:2480-2487, 1995

156. Colombo A, Hall P, Nakamura S, et al: Intracoronary stenting without anticoagulation accomplished with intravascular ultrasound guidance. Circulation 91: 1676-1688, 1995
157. Macaya C, Serruys PW, Ruygrok P, et al: Continued benefit of coronary stenting versus balloon angioplasty: One-year clinical follow-up of Benestent trial. Benestent Study Group. J Am Coll Cardiol 27:255-261, 1996
158. Russo RJ, Schatz RA, Sklar MA, et al: Ultrasound guided coronary stent placement without prolonged systemic anticoagulation. J Am Coll Cardiol 25:50A, 1995 (suppl A)
159. Alfonso F, Rodriguez P, Phillips P, et al: Clinical and angiographic implications of coronary stenting in thrombus-containing lesions. J Am Coll Cardiol 29: 725-733, 1997
160. Sukin CA, Baim DS, Caputo RP, et al: The impact of optimal stenting techniques on cardiac catheterization laboratory resource utilization and costs. Am J Cardiol 79:275-280, 1997
161. Mudra H, Regar E, Klauss V, et al: Serial follow-up after optimized ultrasound-guided deployment of Palmaz-Schatz stents. In-stent neointimal proliferation without significant reference segment response. Circulation 95:363-370, 1997
162. Sankardas MA, McEniery PT, Aroney CN, Bett JHN: Elective implantation of intracoronary stents without intravascular guidance or subsequent warfarin. Cathet Cardiovasc Diagn 37:355-359, 1995
163. Karrillon GJ, Morice MC, Benveniste E, et al: Intracoronary stent implantation without ultrasound guidance and with replacement of conventional anticoagulation by antiplatelet therapy. 30-day clinical outcome of the French Multicenter Registry. Circulation 94: 1519-1527, 1996
164. Goods CM, Al-Shaibi KF, Yadav SS, et al: Utilization of the coronary balloon-expandable coil stent without anticoagulation or intravascular ultrasound. Circulation 93:1803-1808, 1996
165. Serruys PW, Emanuelsson H, van der Giessen W, et al: Heparin-coated Palmaz-Schatz stents in human coronary arteries. Early outcome of the Benestent-II Pilot Study. Circulation 93:412-422, 1996
166. Tobis JM, Colombo A: Do you need IVUS guidance for coronary stent deployment? Cathet Cardiovasc Diagn 37:360-361, 1996
167. Serruys PW, van Hout B, Bonnier H, et al: Randomised comparison of implantation of heparin-coated stents with balloon angioplasty in selected patients with coronary artery disease (Benestent II). Lancet 352:673-681, 1998
168. Kasaoka S, Tobis JM, Akiyama T, et al: Angiographic and intravascular ultrasound predictors of in-stent restenosis. J Am Coll Cardiol 32:1630-1635, 1998
169. Fitzgerald PJ, Hayase M, Mintz GS, et al: CRUISE: Can routine intravascular ultrasound influence stent expansion? Analysis of outcomes. J Am Coll Cardiol 31:396A, 1998 (abstr, suppl A)
170. Russo RJ, Wong SC, Lucisano JE, et al: Angiography versus intravascular ultrasound assessment of coronary stent placement: Observations from the AVID study. J Am Coll Cardiol 31:387A, 1998 (abstr, suppl A)
171. Pritchard CL, Mudd JG, Barner HB: Coronary ostial stenosis. Circulation 52:46-48, 1975
172. Barner HB, Codd JE, Mudd JG, et al: Nonsyphilitic coronary ostial stenosis. Arch Surg 112:1462-1466, 1977
173. Salem BI, Terasawa M, Mathur VS, et al: Left main coronary artery ostial stenosis: Clinical markers, angiographic recognition and distinction from left main disease. Cathet Cardiovasc Diagn 5:125-134, 1979
174. Barner HB, Reese J, Standeven J, et al: Left coronary ostial stenosis: Comparison with left main coronary artery stenosis. Ann Thorac Surg 47:293-296, 1989
175. Tan KH, Sulke N, Taub N, Sowton E: Percutaneous transluminal coronary angioplasty of aorta ostial, non-aorta ostial, and branch ostial stenoses: Acute and long-term outcome. Eur Heart J 16:631-639, 1995
176. de Feyter PJ, van Suylen RJ, de Jaegere PP, et al: Balloon angioplasty for the treatment of lesions in saphenous vein bypass grafts. J Am Coll Cardiol 21:1539-1549, 1993
177. Cook SL, Eigler NL, Shefer A, et al: Percutaneous excimer laser coronary angioplasty of lesions not ideal for balloon angioplasty. Circulation 84:632-643, 1991
178. Jain SP, Liu MW, Dean LS, et al: Comparison of balloon angioplasty versus debulking devices versus stenting in right coronary ostial lesions. Am J Cardiol 79:1334-1338, 1997
179. Zampieri P, Colombo A, Almagor Y, et al: Results of coronary stenting of ostial lesions. Am J Cardiol 73:901-903, 1994
180. Topol EJ, Ellis SG, Fishman J, et al: Multicenter study of percutaneous transluminal angioplasty for right coronary artery ostial stenosis. J Am Coll Cardiol 9:1214-1218, 1987
181. Meier B, Gruentzig AR, King SB, et al: Risk of side branch occlusion during coronary angioplasty. Am J Cardiol 53:10-14, 1984
182. Nakamura S, Hall P, Maiello L, Colombo A: Techniques for Palmaz-Schatz stent deployment in lesions with a large side branch. Cathet Cardiovasc Diagn 34:353-361, 1995
183. Oesterle SN, McAuley BJ, Buchbinder M, Simpson JB: Angioplasty at coronary bifurcations: Single-guide, two-wire technique. Cathet Cardiovasc Diagn 12:57-63, 1986
184. Arora RR, Raymond RE, Dimas AP, et al: Side branch occlusion during coronary angioplasty: Incidence, angiographic characteristics, and outcome. Cathet Cardiovasc Diagn 18:210-212, 1989
185. Mathias DW, Mooney JF, Lange HW, et al: Frequency of success and complications of coronary angioplasty of a stenosis at the ostium of a branch vessel. Am J Cardiol 67:491-495, 1991

186. Weinstein JS, Baim DS, Sipperly ME, et al: Salvage of branch vessels during bifurcation lesion angioplasty: Acute and long-term follow-up. Cathet Cardiovasc Diagn 22:1-6, 1991
187. Brener SJ, Leya FS, Apperson-Hansen C, et al: A comparison of debulking versus dilatation of bifurcation coronary arterial narrowings (from the CAVEAT I Trial). Coronary Angioplasty Versus Excisional Atherectomy Trial-I. Am J Cardiol 78:1039-1041, 1996
188. Aliabadi D, Tilli FV, Bowers TR, et al: Incidence and angiographic predictors of side branch occlusion following high-pressure intracoronary stenting. Am J Cardiol 80:994-997, 1997
189. Fischman DL, Savage MP, Leon MB, et al: Fate of lesion-related side branches after coronary artery stenting. J Am Coll Cardiol 22:1641-1646, 1993
190. Pan M, Medina A, Suarez de Lezo J, et al: Follow-up patency of side branches covered by intracoronary Palmaz-Schatz stent. Am Heart J 129:436-440, 1995
191. Colombo A, Gaglione A, Nakamura S, Finci L: "Kissing" stents for bifurcational coronary lesion. Cathet Cardiovasc Diagn 30:327-330, 1993
192. Di Mario C, Colombo A: Trousers-stents: How to choose the right size and shape? Cathet Cardiovasc Diagn 41:197-199, 1997
193. Schomig A, Neumann FJ, Kastrati A, et al: A randomized comparison of antiplatelet and anticoagulant therapy after the placement of coronary-artery stents. N Engl J Med 334:1084-1089, 1996
194. Leon MB, Baim DS, Popma JJ, et al: A clinical trial comparing three antithrombotic-drug regimens after coronary-artery stenting. Stent Anticoagulation Restenosis Study Investigators. N Engl J Med 339:1665-1671, 1998
195. Park SJ, Park SW, Hong MK, et al: Stenting of unprotected left main coronary artery stenoses: Immediate and late outcomes. J Am Coll Cardiol 31:37-42, 1998
196. Ellis SG, Tamai H, Nobuyoshi M, et al: Contemporary percutaneous treatment of unprotected left main coronary stenoses: Initial results from a multicenter registry analysis 1994-1996. Circulation 96:3867-3872, 1997
197. Ellis S, Nobuyoshi M, Tamai H, et al: Correlates of cardiac death early after hospital discharge in patients who have undergone percutaneous treatment of unprotected left main stenoses—What are the lessons? J Am Coll Cardiol 31:214A, 1998 (abstr, suppl A)
198. Plokker T, Kosuga K, Park S-J, et al: Results of percutaneous intervention for unprotected left main coronary stenoses in surgical and non-surgical candidates. J Am Coll Cardiol 31:138A, 1998 (abstr, suppl A)
199. Tamura T, Kimura T, Nosaka H, Nobuyoshi M: Palmaz-Schatz stenting in unprotected left main coronary artery stenosis: Immediate and follow-up results. J Am Coll Cardiol 31:273A, 1998 (abstr, suppl A)
200. Silvestri M, Barragan P, Simeoni J-B, et al: Stenting of unprotected left main coronary artery stenosis: Immediate and late outcomes. Circulation 98:I-639, 1998 (abstr, suppl I)
201. Wong P, Wong V, Tse KK, et al: A prospective study of elective stenting in unprotected left main coronary disease. Cathet Cardiovasc Intervent 46:153-159, 1999
202. Laruelle CJ, Brueren GB, Ernst SM, et al: Stenting of "unprotected" left main coronary artery stenoses: Early and late results. Heart 79:148-152, 1998
203. Hermiller JB, Buller CE, Tenaglia AN, et al: Unrecognized left main coronary artery disease in patients undergoing interventional procedures. Am J Cardiol 71:173-176, 1993
204. Fisher LD, Judkins MP, Lesperance J, et al: Reproducibility of coronary arteriographic reading in the coronary artery surgery study (CASS). Cathet Cardiovasc Diagn 8:565-575, 1982
205. Lawrie GM, Lie JT, Morris GCJ, Beazley HL: Vein graft patency and intimal proliferation after aortocoronary bypass: Early and long-term angiopathologic correlations. Am J Cardiol 38:856-862, 1976
206. Hamby RI, Aintablian A, Handler M, et al: Aortocoronary saphenous vein bypass grafts. Long-term patency, morphology and blood flow in patients with patent grafts early after surgery. Circulation 60:901-909, 1979
207. Virmani R, Atkinson JB, Forman MB: Aortocoronary saphenous vein bypass grafts. Cardiovasc Clin 18:41-62, 1988
208. Lytle BW, Loop FD, Cosgrove DM, et al: Long-term (5 to 12 years) serial studies of internal mammary artery and saphenous vein coronary bypass grafts. J Thorac Cardiovasc Surg 89:248-258, 1985
209. FitzGibbon GM, Leach AJ, Kafka HP, Keon WJ: Coronary bypass graft fate: Long-term angiographic study. J Am Coll Cardiol 17:1075-1080, 1991
210. Schaff HV, Orszulak TA, Gersh BJ, et al: The morbidity and mortality of reoperation for coronary artery disease and analysis of late results with use of actuarial estimate of event-free interval. J Thorac Cardiovasc Surg 85:508-515, 1983
211. Loop FD, Cosgrove DM: Repeat coronary bypass surgery: Selection of cases, surgical risks, and long-term outlook. Mod Concepts Cardiovasc Dis 55:31-36, 1986
212. Laird-Meeter K, van Domburg R, van den Brand MJ, et al: Incidence, risk, and outcome of reintervention after aortocoronary bypass surgery. Br Heart J 57: 427-435, 1987
213. Douglas JSJ, Gruentzig AR, King SB, et al: Percutaneous transluminal coronary angioplasty in patients with prior coronary bypass surgery. J Am Coll Cardiol 2:745-754, 1983
214. Dorros G, Johnson WD, Tector AJ, et al: Percutaneous transluminal coronary angioplasty in patients with prior coronary artery bypass grafting. J Thorac Cardiovasc Surg 87:17-26, 1984
215. Platko WP, Hollman J, Whitlow PL, Franco I: Percutaneous transluminal angioplasty of saphenous vein graft stenosis: Long-term follow-up. J Am Coll Cardiol 14:1645-1650, 1989

216. Reeves F, Bonan R, Cote G, et al: Long-term angiographic follow-up after angioplasty of venous coronary bypass grafts. Am Heart J 122:620-627, 1991
217. Strumpf RK, Mehta SS, Ponder R, Heuser RR: Palmaz-Schatz stent implantation in stenosed saphenous vein grafts: Clinical and angiographic follow-up. Am Heart J 123:1329-1336, 1992
218. Fenton SH, Fischman DL, Savage MP, et al: Long-term angiographic and clinical outcome after implantation of balloon-expandable stents in aortocoronary saphenous vein grafts. Am J Cardiol 74:1187-1191, 1994
219. Piana RN, Moscucci M, Cohen DJ, et al: Palmaz-Schatz stenting for treatment of focal vein graft stenosis: Immediate results and long-term outcome. J Am Coll Cardiol 23:1296-1304, 1994
220. Wong SC, Baim DS, Schatz RA, et al: Immediate results and late outcomes after stent implantation in saphenous vein graft lesions: The multicenter U.S. Palmaz-Schatz stent experience. The Palmaz-Schatz Stent Study Group. J Am Coll Cardiol 26:704-712, 1995
221. Savage MP, Douglas JSJ, Fischman DL, et al: Stent placement compared with balloon angioplasty for obstructed coronary bypass grafts. Saphenous Vein De Novo Trial Investigators. N Engl J Med 337:740-747, 1997
222. Weintraub WS, Jones EL, Morris DC, et al: Outcome of reoperative coronary bypass surgery versus coronary angioplasty after previous bypass surgery. Circulation 95:868-877, 1997
223. Mintz GS, Pichard AD, Kovach JA, et al: Impact of preintervention intravascular ultrasound imaging on transcatheter treatment strategies in coronary artery disease. Am J Cardiol 73:423-430, 1994
224. Keren G, Douek P, Oblon C, et al: Atherosclerotic saphenous vein grafts treated with different interventional procedures assessed by intravascular ultrasound. Am Heart J 124:198-206, 1992
225. Mendelsohn FO, Foster GP, Palacios IF, et al: In vivo assessment by intravascular ultrasound of enlargement in saphenous vein bypass grafts. Am J Cardiol 76:1066-1069, 1995
226. Painter JA, Mintz GS, Wong SC, et al: Intravascular ultrasound assessment of biliary stent implantation in saphenous vein grafts. Am J Cardiol 75:731-734, 1995
227. Ramee SR, Schatz RA, Carrozza JP, et al: Results of the VeGAS I pilot study of the Possis Coronary Angiojet thrombectomy catheter. Circulation 94:I-619, 1996 (suppl I)
228. Rodes J, Bilodeau L, Bonan R, et al: Angioscopic evaluation of thrombus removal by the POSSIS AngioJet thrombectomy catheter. Cathet Cardiovasc Diagn 43:338-343, 1998
229. van den Bos AA, van Ommen V, Corbeij HM: A new thrombosuction catheter for coronary use: Initial results with clinical and angiographic follow-up in seven patients. Cathet Cardiovasc Diagn 40:192-197, 1997
230. Itoh A, Hall P, Maiello L, et al: Implantation of the peripheral Wallstent for diffuse lesions in coronary arteries and vein grafts. Cathet Cardiovasc Diagn 37:322-330, 1996
231. Gurbel PA, Criado FJ, Curnutte EA, et al: Percutaneous revascularization of an extensively diseased saphenous vein bypass graft with a saphenous vein-covered Palmaz stent. Cathet Cardiovasc Diagn 40:75-78, 1997
232. Gerckens U, Mueller R, Cattelaens N, et al: The new coronary stent graft JoStent: first clinical experience. J Am Coll Cardiol 31:414A, 1998 (abstr, suppl A)
233. Hirshfeld JWJ, Schwartz JS, Jugo R, et al: Restenosis after coronary angioplasty: A multivariate statistical model to relate lesion and procedure variables to restenosis. The M-HEART Investigators. J Am Coll Cardiol 18:647-656, 1991
234. Kuntz RE, Safian RD, Carrozza JP, et al: The importance of acute luminal diameter in determining restenosis after coronary atherectomy or stenting. Circulation 86:1827-1835, 1992
235. Waksman R, Mehran R, Saucedo JF, et al: Balloons PTCA is equivalent to stents in patients with small coronaries: A comparative retrospective matching study. J Am Coll Cardiol 31:275A, 1998 (abstr, suppl A)
236. Savage MP, Fischman DL, Rake R, et al: Efficacy of coronary stenting versus balloon angioplasty in small coronary arteries. Stent Restenosis Study (STRESS) Investigators. J Am Coll Cardiol 31:307-311, 1998
237. Azar AJ, Detre K, Goldberg S, et al: A meta-analysis on the clinical and angiographic outcomes of stents vs PTCA in the different coronary vessel sizes in the Benestent-1 and Stress-1/2 trials. Circulation 92:I-475, 1995 (abstr, suppl I)
238. Akiyama T, Moussa I, Reimers B, et al: Angiographic and clinical outcome following coronary stenting of small vessels: A comparison with coronary stenting of large vessels. J Am Coll Cardiol 32:1610-1618, 1998
239. Lau KW, He Q, Ding ZP, Johan A: Safety and efficacy of angiography-guided stent placement in small native coronary arteries of $<$3.0 mm in diameter. Clin Cardiol 20:711-716, 1997
240. Hoffman R, Mintz GS, Mehran R, et al: Intimal hyperplasia thickness is independent of stent size: A serial intravascular ultrasound study. J Am Coll Cardiol 31:366A, 1998 (abstr, suppl A)
241. Hoffmann R, Mintz GS, Mehran R, et al: Intravascular ultrasound predictors of angiographic restenosis in lesions treated with Palmaz-Schatz stents. J Am Coll Cardiol 31:43-49, 1998
242. Elezi S, Kastrati A, Neumann FJ, et al: Vessel size and long-term outcome after coronary stent placement. Circulation 98:1875-1880, 1998
243. Serruys PW, Foley DP, Kirkeeide RL, King SB: Restenosis revisited: Insights provided by quantitative coronary angiography. Am Heart J 126:1243-1267, 1993
244. Itoh A, Hall P, Maiello L, et al: Coronary stenting of long lesions (greater than 20 mm)—A matched com-

parison of different stents. Circulation 92:I-688, 1995 (abstr, suppl I)
245. Mehran R, Hong MK, Lansky AJ, et al: Vessel size and lesion length influence late clinical outcomes after native coronary artery stent placement. Circulation 96:I-274, 1997 (abstr, suppl 1)
246. Rocha-Singh K, Morris N, Wong SC, et al: Coronary stenting for treatment of ostial stenoses of native coronary arteries or aortocoronary saphenous venous grafts. Am J Cardiol 75:26-29, 1995
247. Mehran R, Mintz GS, Bucher TA, et al: Aorto-ostial instent restenosis: Mechanisms, treatment, and results. A serial quantitative angiographic and intravascular ultrasound study. Circulation 94:I-200, 1996 (suppl I)
248. Goldberg SL, Colombo A, Maiello L, et al: Intracoronary stent insertion after balloon angioplasty of chronic total occlusions. J Am Coll Cardiol 26:713-719, 1995
249. Simes PA, Golf S, Myreng Y, et al: Stenting in Chronic Coronary Occlusion (SICCO): A randomized, controlled trial of adding stent implantation after successful angioplasty. J Am Coll Cardiol 28:1444-1451, 1996
250. Moussa I, Di Mario C, Moses J, et al: Comparison of angiographic and clinical outcomes of coronary stenting of chronic total occlusions versus subtotal occlusions. Am J Cardiol 81:1-6, 1998
251. Rubartelli P, Niccoli L, Verna E, et al: Stent implantation versus balloon angioplasty in chronic coronary occlusions: Results from the GISSOC trial. Gruppo Italiano di Studio sullo Stent nelle Occlusioni Coronariche. J Am Coll Cardiol 32:90-96, 1998
252. Sirnes PA, Golf S, Myreng Y, et al: Sustained benefit of stenting chronic coronary occlusion: Long-term clinical follow-up of the Stenting in Chronic Coronary Occlusion (SICCO) study. J Am Coll Cardiol 32:305-310, 1998
253. Colombo A, Maiello L, Itoh A, et al: Coronary stenting of bifurcation lesions: Immediate and follow-up results. J Am Coll Cardiol 27:277A, 1996 (abstr, suppl A)
254. Hoffmann R, Mintz GS, Dussaillant GR, et al: Patterns and mechanisms of in-stent restenosis. A serial intravascular ultrasound study. Circulation 94:1247-1254, 1996
255. Moussa I, Di Mario C, Moses J, et al: The impact of preintervention plaque area determined by intravascular ultrasound on luminal renarrowing following coronary stenting. Circulation 94:I-261, 1996 (abstr, suppl I)
256. Prati F, Di Mario C, Parma A, et al: The amount of residual plaque burden after coronary stent implantation is associated with the development of late in-stent neointimal proliferation. An intravascular ultrasound study. J Am Coll Cardiol 33:60A, 1999 (abstr, suppl A)
257. Corvaja N, Moses J, Moussa I, et al: Stent restenosis: Where does it occur? An angiographic analysis. Eur Heart J 18:383, 1997 (abstr, suppl)
258. Moussa I, Moses J, Di Mario C, et al: Stenting after optimal lesion debulking (sold) registry. Angiographic and clinical outcome. Circulation 98:1604-1609, 1998
259. Kiesz RS, Rozek MM, Mego DM, et al: Acute directional coronary atherectomy prior to stenting in complex coronary lesions: ADAPTS Study. Cathet Cardiovasc Diagn 45:105-112, 1998
260. Kobayashi Y, Moussa I, Akiyama T, et al: Low restenosis rate in lesions of the left anterior descending coronary artery with stenting following directional coronary atherectomy. Cathet Cardiovasc Diagn 45: 131-138, 1998
261. Bramucci E, Angoli L, Merlini PA, et al: Adjunctive stent implantation following directional coronary atherectomy in patients with coronary artery disease. J Am Coll Cardiol 32:1855-1860, 1998
262. Moussa I, Di Mario C, Moses J, et al: Coronary stenting after rotational atherectomy in calcified and complex lesions. Angiographic and clinical follow-up results. Circulation 96:128-136, 1997
263. Hoffmann R, Mintz GS, Kent KM, et al: Comparative early and nine-month results of rotational atherectomy, stents, and the combination of both for calcified lesions in large coronary arteries. Am J Cardiol 81:552-557, 1998
264. Hoffmann R, Mintz GS, Popma JJ, et al: Treatment of calcified coronary lesions with Palmaz-Schatz stents. An intravascular ultrasound study. Eur Heart J 19: 1224-1231, 1998
265. Ibrahim MA, Kronenberg MW, Boor PJ, et al: Atherectomy and angioplasty improve compliance and reduce thickness of iliac arteries—An in vitro ultrasound study. Circulation 90:I-534, 1994 (abstr, suppl I)
266. Baim DS, Cutlip DE, Sharma SK, et al: Final results of the Balloon vs Optimal Atherectomy Trial (BOAT). Circulation 97:322-331, 1998
267. MacIsaac AI, Bass TA, Buchbinder M, et al: High speed rotational atherectomy: Outcome in calcified and noncalcified coronary artery lesions. J Am Coll Cardiol 26:731-736, 1995
268. Warth DC, Leon MB, O'Neill W, et al: Rotational atherectomy multicenter registry: Acute results, complications and 6-month angiographic follow-up in 709 patients. J Am Coll Cardiol 24:641-648, 1994
269. Reifart N, Vandormael M, Krajcar M, et al: Randomized comparison of angioplasty of complex coronary lesions at a single center. Excimer Laser, Rotational Atherectomy, and Balloon Angioplasty Comparison (ERBAC) Study. Circulation 96:91-98, 1997
270. Sangiorgi G, Rumberger JA, Severson A, et al: Arterial calcification and not lumen stenosis is highly correlated with atherosclerotic plaque burden in humans: A histologic study of 723 coronary artery segments using nondecalcifying methodology. J Am Coll Cardiol 31:126-133, 1998
271. Alfonso F, Macaya C, Goicolea J, et al: Determinants of coronary compliance in patients with coronary artery disease: An intravascular ultrasound study. J Am Coll Cardiol 23:879-884, 1994
272. Fitzgerald PJ, Strut Registry Investigators: Lesion composition impacts size and symmetry of stent

expansion: Initial report from the STRUT Registry. J Am Coll Cardiol 25:49A, 1995 (abstr, suppl A)

273. Kaplan BM, Safian RD, Mojares JJ, et al: Optimal burr and adjunctive balloon sizing reduces the need for target artery revascularization after coronary mechanical rotational atherectomy. Am J Cardiol 78: 1224-1229, 1996

274. Garcia E, Serruys PW, Dawkins K, et al: Benestent-II trial: Final results of visit II & III: A 7-month fol. Eur Heart J 18:350, 1997 (abstr, suppl)

275. Weintraub WS, Mahoney EM, Ghazzal ZMB, et al: Trends in utilization, outcome and cost of coronary stenting. Circulation 98:I-499, 1998 (abstr, suppl I)

276. Bauters C, Hubert E, Prat A, et al: Predictors of restenosis after coronary stent implantation. J Am Coll Cardiol 31:1291-1298, 1998

277. Narins CR, Holmes DRJ, Topol EJ: A call for provisional stenting: The balloon is back. Circulation 97:1298-1305, 1998

278. Frey AW, Mueller C, Hodgson JM: Fewer acute major adverse cardiac events (MACE) by ultrasound guided interventions: Findings from the strategy of intracoronary ultrasound guided PTCA and stenting (SIPS) trial. Eur Heart J 18:133, 1997 (abstr, suppl)

279. Abizaid A, Mehran R, Pichard AD, et al: Results of high pressure ultrasound-guided ''Over-sized'' balloon PTCA to achieve ''stent-like'' results. J Am Coll Cardiol 29:280A, 1997 (abstr, suppl A)

280. Abizaid A, Laird JR Jr, Wu H, et al: Aggressive ultrasound-guided balloon PTCA with provisional stenting: A promising technique to treat patients with left anterior descending lesions. Circulation 98:I-89, 1998 (abstr, suppl I)

281. Rodriguez A, Ayala F, Bernardi V, et al: Optimal coronary balloon angioplasty with provisional stenting versus primary stent (OCBAS): Immediate and long-term follow-up results. J Am Coll Cardiol 32: 1351-1357, 1998

282. Ellis SG, Roubin GS, King SB, et al: Importance of stenosis morphology in the estimation of restenosis risk after elective percutaneous transluminal coronary angioplasty. Am J Cardiol 63:30-34, 1989

283. Tenaglia AN, Zidar JP, Jackman JDJ, et al: Treatment of long coronary artery narrowings with long angioplasty balloon catheters. Am J Cardiol 71:1274-1277, 1993

284. Fernandez-Ortiz A, Perez-Vizcayno MJ, Goicolea J, et al: Should we stent small coronary vessels? Comparison with conventional balloon angioplasty. Eur Heart J 18:26, 1997 (abstr, suppl)

285. Keane D, Azar AJ, de Jaegere P, et al: Clinical and angiographic outcome of elective stent implantation in small coronary vessels: An analysis of the BENESTENT trial. Semin Intervent Cardiol 1:255-262, 1996

286. De Gregorio J, Kobayashi Y, Albiero R, et al: Long term results of IVUS guided PTCA and spot stenting in long lesions and small vessels. Circulation 98:I-90, 1998 (abstr, suppl I)

287. Kobayashi N, De Gregorio J, Adamian M, et al: Dissections post coronary stenting: Is it worth extending your stent length to cover all dissections? J Am Coll Cardiol 33:58A, 1999 (abstr, suppl A)

288. Yokoi H, Kimura T, Nakagawa Y, et al: Long-term clinical and quantitative angiographic follow-up after the Palmaz-Schatz stent restenosis. J Am Coll Cardiol 27:224A, 1996 (abstr, suppl A)

289. Reimers B, Moussa I, Akiyama T, et al: Long-term clinical follow-up after successful repeat percutaneous intervention for stent restenosis. J Am Coll Cardiol 30:186-192, 1997

290. Schiele F, Meneveau N, Vuillemenot A, et al: Treatment of in-stent restenosis with high speed rotational atherectomy and IVUS guidance in small $<$3.0 mm vessels. Cathet Cardiovasc Diagn 44:77-82, 1998

291. Goldberg SL, Shawl F, Buchbinder M, et al: Rotational atherectomy for in-stent restenosis: The BARASTER registry. Circulation 96:I-80, 1997 (abstr, suppl I)

292. Hamm CW, Simon R, Seabra Gomes RJ, et al: Laser angioplasty for within stent restenosis—Final results of the LARS surveillance study. J Am Coll Cardiol 31:143A, 1998 (abstr, suppl A)

293. Koster R, Hamm CW, Terres W, et al: Treatment of in-stent coronary restenosis by excimer laser angioplasty. Am J Cardiol 80:1424-1428, 1997

294. Nakamura M, Suzuki T, Matsubara T, et al: Results of cutting balloon angioplasty for stent restenosis. Japanese multicenter registry. J Am Coll Cardiol 31:235A, 1998 (abstr, suppl A)

295. Chevalier B, Royer T, Guyon P, Glatt B: Treatment of instent restenosis: Short and midterm results of a pilot randomized study between balloon and cutting balloon. J Am Coll Cardiol 33:62A, 1999 (abstr, suppl A)

296. Debbas N, Stauffer JC, Eeckhout E, et al: Stenting within a stent: Treatment for repeat in-stent restenosis in a venous graft. Am Heart J 133:460-463, 1997

297. Cecena FA: Stenting the stent: Alternative strategy for treating in-stent restenosis. Cathet Cardiovasc Diagn 39:377-382, 1996

298. Goldberg SL, Loussararian AH, Di Mario C, et al: Stenting for in-stent restenosis. Circulation 96:I-88, 1997 (suppl I)

299. Mehran R, Abizaid AS, Mintz GS, et al: Mechanisms and results of additional stent implantation to treat focal in-stent restenosis. J Am Coll Cardiol 31:455A, 1998 (suppl A)

300. Lefevre T, Louvard Y, Morice MC, et al: In-stent restenosis: Should we stent? A single center prospective study. Circulation 96:I-88, 1997 (abstr, suppl I)

301. Elezi S, Kastrati A, Schuhlen H, et al: Stenting for restenosis of stented lesions: Acute and 6 months clinical and angiographic follow-up. Circulation 96:I-88, 1997 (abstr, suppl I)

302. Teirstein PS, Massullo V, Jani S, et al: Catheter-based radiotherapy to inhibit restenosis after coronary stenting. N Engl J Med 336:1697-1703, 1997

303. Moris C, Alfonso F, Lambert JL, et al: Stenting for coronary dissection after balloon dilation of in-stent restenosis: Stenting a previously stented site. Am Heart J 131:834-836, 1996

304. Shiran A, Waksman R, Abizaid A, et al: Is recurrent in-stent restenosis INSTANT restenosis? An intravascular ultrasound study. Circulation 96:I-87-I-88, 1997 (abstr, suppl I)

305. Tanguay JF, Armstrong BA, Fortin DF, et al: Assessment of coronary stent recoil by quantitative coronary angiography: Does design make a difference? Circulation 90:I-488, 1994 (abstr, suppl I)

306. Dussaillant GR, Mintz GS, Pichard AD, et al: Small stent size and intimal hyperplasia contribute to restenosis: A volumetric intravascular ultrasound analysis. J Am Coll Cardiol 26:720-724, 1995

307. Koch L, Roth T: Technical aspects of intravascular ultrasound, in Erbel R, Roelandt JRTC, Ge J, Goerge G (eds): Intravascular Ultrasound. London, UK, Martin Dunitz Limited, 1998, pp 17-30

308. Bom N, Lancee CT, Gussenhoven EJ, et al: Basic principles of intravascular ultrasound imaging, in Tobis JM and Yock PG (eds): Intravascular Ultrasound Imaging. New York, NY, Churchill Livingstone, 1992, pp 7-15

309. Talley JD, Mauldin PD, Becker ER, et al: Cost and therapeutic modification of intracoronary ultrasound-assisted coronary angioplasty. Am J Cardiol 77:1278-1282, 1996

310. Frey AW, Mueller C, Roskamm H, Hodgson JM: Additional costs of intracoronary ultrasound (ICUS) in routine use: Findings from the strategy of ICUS guided PTCA and stenting (SIPS) trial. Eur Heart J 18:133, 1997 (abstr, suppl)

311. Bailey SR: IVUS imaging: Is it cost-effective? Intravasc Imaging 2:82-84, 1998