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CLINICAL INVESTIGATIONS

Mechanism of high-speed rotational atherectomy and adjunctive balloon angioplasty revisited by quantitative coronary angiography: Edge detection versus videodensitometry

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High-speed rotational coronary atherectomy (RA) is primarily used to treat complex lesions. Quantitative angiographic analysis of such complex lesions by edge detection is often unsuitable, whereas videodensitometry, measuring vessel dimensions independently of the target stenosis contours, may offer potential advantages. To gain insight into the operative mechanism of RA and to study the agreement between the two quantitative angiographic methods in measuring the minimal luminal cross-sectional area, the edge detection and videodensitometry techniques were applied to coronary angiograms of 21 lesions in 19 patients with symptoms who underwent successful RA and balloon angioplasty (BA). Obstruction diameter as determined by edge detection increased from 1.00 ± 0.31 mm before intervention to 1.35 ± 0.29 mm after RA ($p < 0.001$) and further increased to 1.74 ± 0.33 mm after adjunctive BA ($p < 0.001$). The mean between-method difference (edge detection minus videodensitometry) was 0.34 mm^2 before intervention, 0.13 mm^2 after RA, and 0.09 mm^2 after adjunctive BA (not significant). The standard deviation of the differences decreased from ±0.87 mm^2 before intervention to ±0.80 mm^2 after RA (not significant) and increased after BA significantly to ±1.21 mm^2 ($p < 0.05$). Thus edge detection and videodensitometry provided equivalent immediate angiographic results after RA and adjunctive BA. The good agreement after RA may reflect the operative mechanism of RA, which by ablation of noncompliant plaque material yields a circular symmetric lumen with smooth surface. The increased dispersion of the between-method differences observed after adjunctive BA presumably results from dissections, plaque ruptures, and loss of luminal smoothness after balloon dilatation. (Am Heart J 1995;130:405-12.)

High-speed rotational atherectomy (RA) is an interventional device that ablates and pulverizes noncompliant coronary plaque material by high-frequency rotation of a diamond-coated burr.[1] It may be used as a stand-alone procedure for treatment of coronary lesions but is frequently used as a primary device and is subsequently combined with balloon angioplasty (BA) or directional atherectomy.[2-13] It has by preference been applied to diffusely diseased and calcified coronary arteries with complex lesion architecture.[5, 9-17] To assess the results of intracoronary interventions objectively, reliably, and reproducibly, a computerized semiautomated quantification of the lumen should be applied to the cineangiograms.[18-24]

There are two principal approaches of computerized angiographic analysis: edge detection and videodensitometry. Whereas edge detection is based on an automatic contour detection of the geometric vessel shape, videodensitometry is independent of luminal shape of the target stenosis and is based on the relation between the optical density of the contrast-enhanced lumen and the absolute vessel dimensions. In clinical practice edge detection is still considered the standard approach of quantitative angiographic analysis, whereas the value of videodensitometric assessments remains controversial.[20, 22, 25-36] To gain

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Table I. Edge detection before intervention, after rotational atherectomy, and after adjunctive balloon angioplasty

	Before intervention	*After RA*	*After BA*
Reference diameter (mm)	2.68 ± 0.52	2.68 ± 0.46	2.71 ± 0.49
Obstruction diameter (mm)	1.00 ± 0.31*	1.35 ± 0.29*	1.74 ± 0.33*
Diameter stenosis (%)	61.7 ± 12.2*	49.38 ± 7.41*	35.4 ± 10.12*

*$p < 0.001$ (before intervention vs after RA, before intervention vs after adjunctive BA, and after RA vs after adjunctive BA).

insight into the operative mechanism and the postprocedural luminal geometry after RA and BA and to study the agreement between the two quantitative angiographic methods in measuring the minimal luminal cross-sectional area,[37] edge detection and videodensitometry were applied to coronary angiograms that were acquired before intervention, after RA, and after adjunctive BA.

METHODS

Study patients and qualitative lesion characteristics. Nineteen patients, 12 men and seven women with a mean age of 62.4 years (range, 48 to 73 years) who had 21 calcified American College of Cardiology/American Heart Association (ACC/AHA) type B2 or C lesions[38, 39] that had been successfully treated by RA and adjunctive BA were studied. All lesions were nonostial and located in native coronary arteries, mostly with angiographic evidence of diffuse plaque calcification (18 of 21 lesions). Location of the lesion was right coronary artery (RCA) in 10 cases, left anterior descending coronary artery (LAD) in nine, and left circumflex coronary artery (LCX) in two. In two patients two distinct lesions were individually treated (lesions 9 and 10 and lesions 13 and 14, respectively). The treated segments (Table I) are indicated according to the AHA grading system,[40] and coronary dissections are indicated according to the morphologic classification of the National Heart, Lung and Blood Institute (NHLBI).[41]

Description of the interventional procedure. After pretreatment was performed with 250 mg acetylsalicylic acid and 10,000 U heparin, the coronary artery ostium was intubated with 8F to 10F standard guiding catheters. Intracoronary injection of isosorbide dinitrate was performed to prevent possible coronary spasm, and a 0.009 inch Rotablator guidewire (Heart Technology Inc., Bellevue, Wash.) was advanced distal to the lesion. The rotational ablation device, an air-turbine driven burr (Rotablator, Heart Technology Inc.) of different sizes (diameter, 1.25 to 2.5 mm) with 10 μm diamond chips on the distal portion, was tracked proximal to the lesion and then slowly advanced during high-speed rotation of the burr at 170,000 to 200,000 rpm.

Plaque material was thereby ablated and pulverized with the stepped-burr technique aiming at a maximal burr size of approximately 75% of the adjacent reference segments. After successful high-speed RA was performed, the system was exchanged for a BA catheter. To improve the final result adjunctive balloon angioplasty[42] was performed at the site of the artery, which had been previously treated by RA. During the entire cardiac catheterization procedure the activated clotting time (ACT) was serially measured, and intravenous heparin was administered to maintain the ACT at 300 seconds.

Angiographic image acquisition. During initial coronary angiography three views with orthogonal projections and an angle of at least 40 degrees between each were acquired. The lesion characteristics were derived from these views. Quantitative angiographic analysis was performed after RA treatment and adjunctive BA in the single worst view. To allow a reliable off-line quantification of the luminal dimensions by videodensitometry, frames with a homogeneous and complete opacification of the coronary lumen at the segment of interest were selected for analysis.

Quantitative coronary angiography. The minimal luminal area was determined by edge detection and videodensitometry. The quantitative analysis of the cineangiograms was performed off-line with the computer-assisted cardiovascular angiographic analysis system (CAAS, Pie Medical, Maastricht, The Netherlands), previously described in detail.[30, 32, 43, 44] First, an end-diastolic cineframe was selected for off-line analysis. A 6.9 × 6.9 mm region of interest comprising a chosen coronary segment was then selected from the 18 × 24 mm image area on the 35 mm cineframe and was digitized into a 512 × 512 pixel matrix with 258 gray levels (8 bits) with the use of a high-fidelity CCD-camera. Edge detection and videodensitometry were then performed.

Edge detection. Based on the weighted sum of the first and second derivative functions applied to the digitized brightness silhouette, automatic detection of the coronary artery contours was performed. The diameter function of the coronary artery lumen was determined by computing the shortest distances between the edge points of the left and right contours.[43] The interpolated reference diameter was based on a computerized estimation of the original arterial dimension at the site of the obstruction. After the procedure was performed, the diameter of the guiding catheter was measured by an electronic precision micrometer (Mitotoyo OP-1HS Tokyo, Japan; accuracy 0.001 mm). With the measured dimensions of the guiding catheter used for calibration, absolute values of the minimal diameter of the stenosis and reference vessel diameter were calculated after correction for pincushion distortion was performed. The minimal cross-sectional area of the

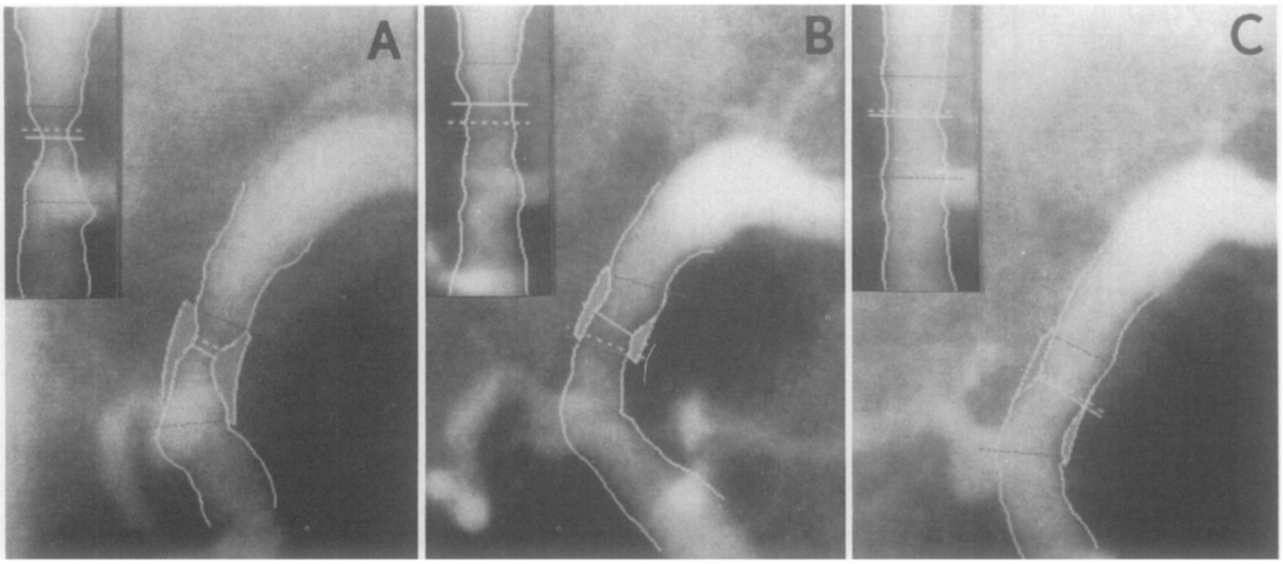

Fig. 1. Representative quantitative angiographic assessment of lesion in proximal right coronary artery before intervention **(A)**, after high-speed rotational atherectomy **(B)**, and after adjunctive balloon angioplasty **(C)**.

narrowest segment and the interpolated percent area stenosis were subsequently calculated assuming a circular model (πr^2).

Videodensitometry. In contrast to edge detection, which considers only changes in pixel brightness, videodensitometry makes use of the absolute pixel brightness values. To obtain a cross-sectional area function of the lumen along a segment of interest from a density silhouette of an opacified coronary artery, brightness levels have to be calibrated in terms of the amount of x-ray absorption with Lambert Beer's law. Corrections for spatially variant responses in the imaging chain and processing of the cinefilm were performed. The contours and diameter values of the analyzed coronary segment were obtained from the CAAS described previously. The profile of brightness of multiple scan-lines perpendicular to the local center-line direction of the coronary artery was then measured. Consequently this brightness profile was transformed by a logarithmic transfer function into an absorption profile (gross absorption). By computing the linear regression line through the background points directly right and left of the contours of the coronary silhouette, the background contribution was estimated and subtracted from the previous gross absorption profile to obtain the net cross-sectional absorption profile within the vessel contours. Thus a luminal cross-sectional area function along the analyzed coronary artery segment was obtained. Calibration of the videodensitometric area values was performed by comparing the luminal area of the reference calculated from the diameter measurements assuming a circular lumen configuration with the corresponding densitometric area values of the reference. The whole process of measuring luminal cross-sectional area by videodensitometry has previously been assessed in vitro by perspex models of coronary artery obstructions[45] and in vivo with stenosis phantoms, which were introduced in porcine coronary arteries.[25]

Statistics. Minimal luminal cross-sectional areas were measured by edge detection and videodensitometry in the single worst view. Mean and standard deviation of the between-method differences were determined at each of the three distinct times of angiographic assessment. Analysis of variance was performed to compare minimal luminal area measurements obtained from edge detection and videodensitometry before intervention, after rotational coronary atherectomy, and after adjunctive balloon angioplasty. When differences were found, two-tailed paired *t* tests were applied, and a statistical probability <0.05 was considered significant. Correlation coefficients (r) were calculated for the three distinct times of angiographic assessment to assess the strength of the relation between edge detection and videodensitometry in determining the minimal luminal cross-sectional area. According to the statistical approach of Bland and Altman,[46] the agreement between both methods was assessed by determining the mean and standard deviation of the between-method differences (edge detection minus videodensitometry). This procedure was performed at each of the three distinct times of study by computing the sum of the individual between-method differences. The variances of the between-method differences before intervention, after RA, and after BA were tested against each other with Pitman's Test.[47]

RESULTS

At the three distinct times of angiographic assessment complete angiographic perfusion was found in all coronary arteries except one, which was initially occluded. The reference diameter of the analyzed

Table II. Minimal luminal cross-sectional area measurements (mm^2) by edge detection and videodensitometry

Lesion no.	*Vessel segment*	*Before intervention*			*After RA*			*After adjunctive BA*		
		ED	*VD*	*Difference*	*ED*	*VD*	*Difference*	*ED*	*VD*	*Difference*
1	7	0.79	0.04	0.75	2.66	1.42	1.24	3.14	3.63	−0.49
2	1	0.49	−1.08	1.57	2.54	0.66	1.88	2.46	2.03	0.43
3	13	0.93	0.73	0.20	1.56	1.84	−0.28	2.24	3.01	−0.77
4	13	0.72	0.17	0.55	1.45	1.32	0.13	3.08	2.30	0.78
5	1	0.71	0.51	0.20	1.11	1.16	−0.05	3.33	2.77	0.56
6	6	0.87	1.04	−0.17	1.37	1.27	0.10	2.03	1.32	0.71
7	6	0.92	1.10	−0.18	0.77	1.52	−0.75	2.80	2.29	0.51
8	1	1.35	1.23	0.12	1.37	0.97	0.40	3.36	2.38	0.98
9	7	1.63	−0.71	2.34	1.19	1.21	−0.02	3.02	2.81	0.21
10	8	0.82	0.49	0.33	1.25	1.21	0.04	1.47	1.96	−0.49
11	2	0.52	0.54	−0.02	1.25	0.88	0.37	1.57	1.96	−0.39
12	1	—*	—	—	0.55	0.95	−0.40	2.11	2.00	0.11
13	2	1.47	0.44	1.03	1.58	1.06	0.52	1.47	0.45	1.02
14	3	0.53	0.43	0.10	0.87	0.46	0.41	2.60	2.88	−0.28
15	2	1.52	3.01	−1.49	3.70	5.84	−2.14	5.35	9.67	−4.32
16	2	0.75	1.35	−0.60	1.61	1.59	0.02	2.32	1.58	0.74
17	6	1.33	−0.56	1.89	1.25	1.18	0.07	1.77	0.53	1.24
18	6	0.83	1.01	−0.18	1.37	1.67	−0.30	1.86	2.78	−0.92
19	6	0.52	0.56	−0.04	1.63	1.19	0.44	1.65	1.51	0.14
20	2	0.92	1.10	−0.18	1.39	1.59	−0.20	2.75	2.17	0.58
21	7	0.49	−0.10	0.59	1.15	−0.05	1.20	1.11	−0.43	1.54
Mean		0.90	0.57	0.34	1.50	1.38	0.13	2.45	2.36	0.09
SD		0.36	0.88	0.87	0.70	1.11	0.80	0.94	1.92	1.21

ED, Edge detection; *VD*, videodensitometry.
*Initially occluded coronary artery.

coronary arteries was 2.68 ± 0.52 mm (range, 2.09 to 4.02 mm), and the lesion length was 7.45 ± 2.81 mm (range, 4.30 to 13.46 mm). The obstruction diameter increased from 1.00 ± 0.31 mm before intervention to 1.35 ± 0.29 mm after RA ($p < 0.001$) (Table I). After adjunctive BA was performed, the obstruction diameter was further enlarged to 1.74 ± 0.33 mm ($p < 0.001$). Interventional therapy reduced the diameter stenosis from 61.7% ± 12.2% before therapy to 49.38% ± 7.41% after RA ($p < 0.001$) and to 35.4% ± 10.12% after adjunctive BA ($p < 0.001$) (Fig. 1).

In Table II the individual data of the minimal luminal cross-sectional area measured by edge detection and videodensitometry and the individual and mean between-method differences are presented for the three distinct times of angiographic measurement. The agreement between both diagnostic methods before and after RA and after BA is illustrated in Fig. 2. At each of the three times of angiographic study, minimal luminal cross-sectional area was determined to be greater by edge detection than by videodensitometry. Mean difference was lower after RA and after adjunctive BA (0.13 mm^2 and 0.09 mm^2, respectively) compared with preintervention (0.34 mm^2). The standard deviation of the between-method differences, representing the variability, decreased from 0.87 mm^2 before intervention to 0.80 mm^2 after RA (not significant). After adjunctive BA was performed, the standard deviation of the between-method differences increased significantly to 1.21 mm^2 (after RA vs after BA, $p < 0.05$). The correlation coefficient r of measurements by edge detection and videodensitometry increased from 0.22 before intervention to 0.70 after RA and to 0.86 after adjunctive BA. In all the cineangiograms no evidence of dissection was seen after RA was performed, but after adjunctive BA was performed, six (29%) of the previously dilated coronary segments showed characteristics of coronary dissection (three NHLBI dissection-type A, two type B, and one type D).

DISCUSSION

Two findings of this study should be emphasized. First, no significant difference of the mean between-method difference (edge detection minus videodensitometry) was seen after RA and after adjunctive BA were performed. Second, the standard deviation of the between-method differences increased significantly after BA was performed. These results may well reflect the operative mechanisms of the two devices, but the accuracy of the two quantitative angiographic techniques cannot be determined and compared, because the true dimension of the vessels is unknown.[48, 49]

Limitations of videodensitometry. In some cases videodensitometry provides negative values of the minimal luminal cross-sectional area. Negative values are more frequently found in coronary angiograms with side-branches or other radiopaque structures, interfering with the densitometric measurements by increasing the brightness profile of the reference segment. This overestimation of the reference brightness profile results in an underestimation of the minimal luminal cross-sectional area.[26] In this study negative values were more frequently found during the angiographic assessment before intervention, explaining the positive value of the mean between-method difference (edge detection minus videodensitometry). This finding concurs with previous reports that describe an increased incidence of negative values of minimal luminal cross-sectional area obtained from videodensitometry in smaller luminal dimensions.[26] In this study only one negative value of the minimal luminal cross-sectional area was obtained after RA and after adjunctive BA, respectively. This limitation of videodensitometry should soon be overcome by the incorporation of a background subtraction algorithm that corrects for the contribution of side-branches to the brightness intensity.[50]

Quantitative coronary angiography in complex lesions. The low correlation of the quantitative angiographic measurements before intervention was striking. Several reasons such as the high rate of complex and narrow lesions in small, calcified, and tortuous coronary arteries and the higher incidence of negative values of minimal luminal cross-sectional area before intervention might be responsible for this finding.[51] A new approach in quantitative coronary angiography is the gradient field transform. With the use of this new algorithm promising results in the quantification of complex coronary artery lesions have recently been reported.[52]

Mechanism of rotational atherectomy. Edge detection is a quantitative angiographic method that is based on a computerized detection of the geometric contours of the vessel lumen, whereas videodensitometry operates independently of the geometric stenosis profile by using the optical density of the opacified coronary artery.[27, 29, 30, 32, 35, 50] Differences between the results obtained by the two methods are less likely to be expected in a circular symmetric lumen, because luminal circularity is an elementary assumption in the calculation of minimal luminal cross-sectional area by edge detection in a single view. Thus less discrepancy between edge detection and videodensitometry was expected after plaque ablation by RA, and accordingly, good agreement of the two quantitative angiographic methods was found after RA. The presumption that the good

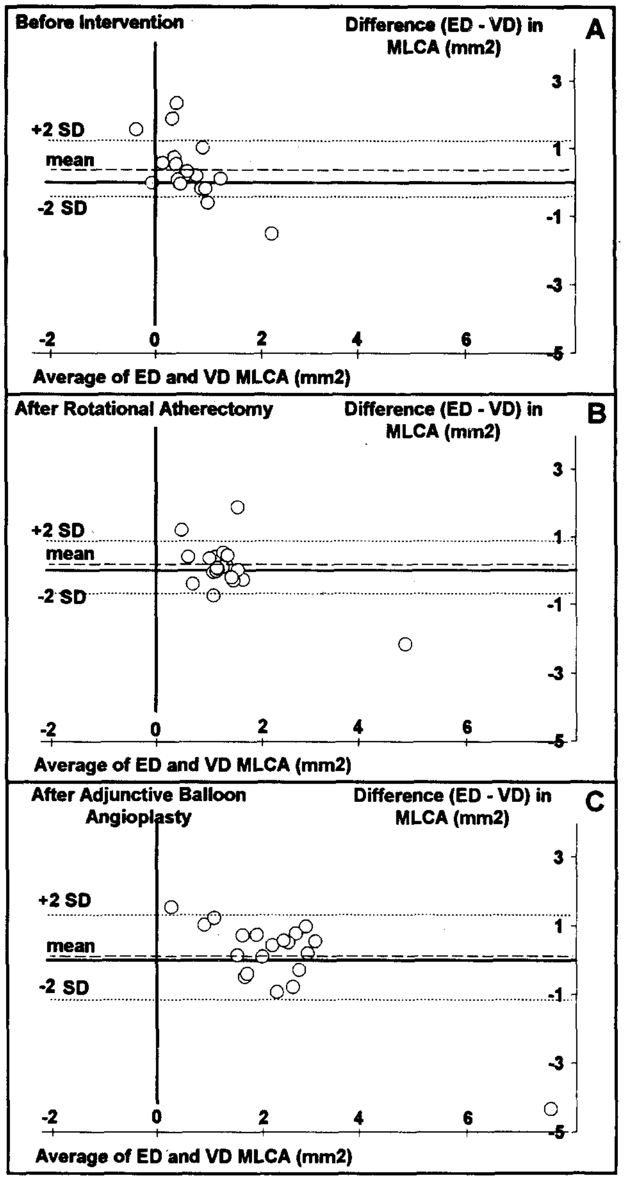

Fig. 2. Agreement of edge detection *(ED)* and videodensitometry *(VD)* in measuring minimal luminal cross-sectional area *(MLCA)*. Mean between-method difference (ED minus VD) was lower after rotational atherectomy *(B)* and adjunctive balloon angioplasty *(C)* (0.13 mm^2 and 0.09 mm^2, respectively) compared with before intervention *(A)* (0.34 mm^2). Standard deviation *(SD)* of between-method differences after rotational atherectomy remained similar to before intervention (0.80 mm^2 and 0.87 mm^2, respectively), whereas significant increase ($p < 0.05$) was found after adjunctive balloon angioplasty (1.21 mm^2).

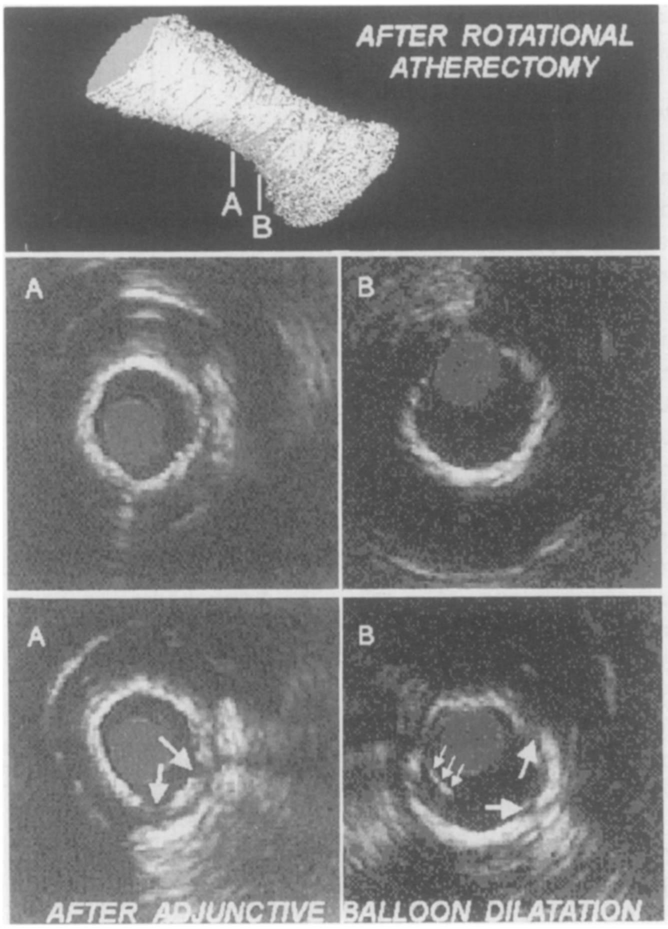

Fig. 3. Example of stenotic, circumferentially calcified proximal segment of left anterior descending coronary artery treated by rotational atherectomy and adjunctive balloon angioplasty. Intravascular ultrasound *(IVUS)* study reflects operative mechanism of both interventional techniques. Positions of mid-stenotic *(A)* and proximal *(B)* cross-sections, displayed in *mid* and *lower panels,* are indicated in three-dimensional IVUS lumen cast *(upper panel)*, reconstructed from images acquired during motorized pull-back of IVUS catheter after rotational atherectomy. In cross-sectional images and in lumen cast, relatively smooth and circular lumen shape was found, whereas adjunctive balloon dilatation resulted in plaque rupture and dissection *(large arrowheads)* and intimal flaps *(small arrowheads).*

agreement resulted from plaque ablation providing a circular lumen shape with a smooth surface,[53] as confirmed by intracoronary ultrasonography[7, 54] (Fig. 3), is supported by our previous observations describing increased agreement and correlation of the two angiographic techniques after coronary stenting.[32]

Mechanism of adjunctive balloon dilatation. In this study the incidence of angiographically detected dissection after adjunctive BA was similar to that observed after primary BA.[55, 56] Dissections are less frequent after RA than after BA,[11] and in the Rotational Atherectomy Multicenter Registry of 709 patients, dissections were found in 10.5% of cases.[12] Adjunctive BA increases the incidence of dissections after RA,[57] but on the other hand BA can be used for management of coronary dissections after RA.[9] Because the main operative mechanism of BA is rupture and dissection of the atherosclerotic plaque, a less circular and less smooth vessel shape would be expected after balloon dilatation, thus explaining the increased standard deviation of the between-method differences found after adjunctive BA. This increased variability of the between-method differences after adjunctive BA is in accordance with our previous studies performed after BA.[30, 32]

Conclusions. When the immediate results after RA and adjunctive BA are assessed, edge detection and videodensitometry provide equivalent information. As with previous clinical studies investigating the dimension of coronary lesions, the true absolute size of the coronary vessels is unknown, and it is thus not possible to define whether the accuracy of one of the techniques is superior to the other. Good agreement of edge detection and videodensitometry was found after RA, reflecting the operative mechanism of RA, which provides a circular lumen shape with a smooth surface by ablation and pulverization of noncompliant plaque material. Adjunctive BA further enlarged the minimal luminal cross-sectional area but also increased the variability of the differences between the measurements provided by edge detection and videodensitometry. This increase is believed to result from dissections, plaque ruptures, and loss of luminal smoothness produced by balloon angioplasty.

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