Coronary Atherectomy
Clinical, Angiographic, and Histological Findings and Observations Regarding Potential Mechanisms

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Between August 5, 1988 and August 1, 1989, we attempted percutaneous directional coronary atherectomy of 76 lesions, including 42 primary lesions and 34 restenosis lesions that developed after one or more prior interventions. The procedure was successful in 67 lesions (88%), with a decrease in diameter stenosis from 80±11% to 5±15% after atherectomy (p<0.01). One or more complications occurred in six patients (9%), including non-Q wave myocardial infarction (three patients, 4.5%), femoral arterial injury requiring surgical repair (two patients, 3%), and proximal dissection leading to emergency bypass surgery (one patient, 1.5%). Despite these favorable acute results, the 6-month lesion restenosis rate was 30% by life-table analysis. Light microscopy of retrieved tissue revealed atherosclerotic plaque in 94%, media in 67%, and adventitia in 27%. Intimal proliferation was present in 97% of the restenosis lesions but was also evident in 33% of primary lesions. Tissue weight from 27 lesions averaged 18.5 mg (range, 5.8-45.1 mg), which is not adequate to explain the entire angiographic improvement. Thus, part of the improvement in lumen diameter appears to be due to mechanical dilatation rather than to tissue removal alone. Atherectomy can predictably treat selected coronary lesions with overall safety comparable to that of conventional balloon angioplasty, although the procedure as currently performed does not derive all of its benefit from tissue removal and does not appear to prevent restenosis. (Circulation 1990;82:69-79)

Since the development of coronary angioplasty in 1977, there has been progressive refinement in balloon dilatation equipment and technique. Gruentzig et al's early data1 and those from the original 1979-1981 National Heart, Lung, and Blood Institute Angioplasty Registry2 showed a primary success rate of 63% for proximal, discrete, noncalcified, and nontotal stenoses of a single coronary artery, but recent technologic advances and greater operator experience have produced a primary success rate exceeding 90% and an emergency coronary artery bypass graft surgery rate of less than 3% despite application of angioplasty in patients with progressively more complex coronary anatomy.3-11 Two main limitations of coronary angioplasty, however, continue to be reliable dilatation of eccentric lesions and prevention of restenosis, which occurs after 20-30% of routine12-14 and 40-50% of total occlusion, saphenous vein bypass graft, or multivessel dilatations.6,15-20

Directional transluminal atherectomy is one of a variety of new interventional catheter technologies that have been introduced in the hope of addressing the residual problems of conventional balloon dilatation. It has proven to be safe and effective in patients with occlusive peripheral vascular disease21 and has recently been introduced as an investiga-tional treatment for coronary artery disease.22 The purpose of this study was to evaluate the immediate angiographic results, histological findings, and early follow-up of the 67 patients treated with directional coronary atherectomy during our first year's experience with this technique.

Methods

Patient Population

Between August 5, 1988, and August 1, 1989, coronary atherectomy was attempted in 67 patients, who represented 9.5% of the patient population referred for coronary intervention at our institution during that time period. They were selected for
atherectomy rather than conventional balloon angioplasty based on the presence of a localized stenosis in the proximal or midportion of a vessel whose reference segment diameter was 2.5 mm or more. The 56 men and 11 women had a mean age of 57±11 years, and Canadian Heart Association classification was I (5%), II (33%), III (28%), and IV (34%). A history of prior myocardial infarction was elicited in 30 patients (45%). Significant coronary artery disease (>70% diameter stenosis) was limited to one vessel in 45 patients (67%), two vessels in 11 patients (16%), and three vessels in 11 patients (16%). Ten patients had previously undergone coronary artery bypass graft surgery.

Coronary atherectomy was used to treat 76 lesions—42 primary (de novo) and 34 restenosis lesions that had developed 1–6 months after prior conventional coronary angioplasty (31 patients), intracoronary stent placement (one patient), or laser balloon angioplasty (two patients). The treated lesions were located in the left anterior descending (50 lesions), circumflex (10 lesions), or right coronary (seven lesions) artery and a saphenous vein bypass graft (nine lesions). One or more of the following features were present in 68 (89%) of the 76 lesions: prior restenosis (34 lesions); vein graft disease (nine lesions); unfavorable lesion morphology for conventional dilatation, including ulceration (12 lesions); marked eccentricity (47 lesions); ostial location (seven lesions); marked angulation (four lesions); length 20 mm or more (12 lesions); or total occlusion (two lesions). All coronary atherectomy procedures were performed under a protocol approved by the Committee on Clinical Investigations at Beth Israel Hospital.

Coronary Atherectomy Procedure

The atherectomy catheter (Simpson AtheroCath, Devices for Vascular Intervention, Redwood City, California) is a cutting and retrieval system that consists of a rotating cup-shaped cutter contained within a windowed cylindrical housing, to which an opposing contrast-filled 2.0-mm balloon is attached (Figure 1). It differs from the peripheral device in its smaller size and hollow cutter torque tubing, which allows advancement over a 0.014-in. guidewire.

After baseline coronary angiography (with a 9F Judkins guiding catheter), a specially shaped 11F atherectomy guiding catheter (constructed with gentle curves rather than angles to facilitate passage of the rigid atherectomy housing) was positioned at the coronary ostium through an 11F femoral arterial sheath (Cook, Bloomington, Indiana). A 0.014-in. high-torque floppy guidewire (Advanced Cardiovascular Systems, Temecula, California) was manipulated across the stenosis, and the atherectomy catheter (5F, 6F, or 7F) was advanced across the lesion using gentle forward pressure and continuous rotation. Once the device was in position, multiple cuts (usually in quadrants) were made with different radial orientations of the cutting window as monitored by fluoroscopy. Balloon inflation pressures of 20–30 psi were used to
press the window against the plaque while the motor-driven cutter was advanced across the window. The device was withdrawn and emptied every four to six cuts and then reintroduced (two to four times) until the angiographic result was optimal or no more tissue could be removed from the vessel wall.

The number of passes and the final size of the device were determined by the size of the reference segment and the presence of any angiographic residual stenosis after initial atherectomy cuts. A 6F device was used primarily in vessels with reference diameter of less than 3.0 mm, whereas a 7F device was used when the reference segment was 3.0 mm or more in diameter or when there was a persistent residual stenosis after use of a 6F device with balloon inflation pressures up to 40 psi. Successful atherectomy was defined as tissue removal, a residual diameter stenosis of less than 50% without having to use postatherectomy balloon dilatation, and absence of a major complication (death, Q wave myocardial infarction, or emergency coronary artery bypass graft surgery).

Medications

Each patient was pretreated with 325 mg aspirin daily and 50 mg dipyridamole four times daily beginning at least 24 hours before the procedure and continued indefinitely after discharge. After insertion of the arterial sheath, 10,000 units i.v. heparin was administered. Additional heparin boluses (2,500 units) were given every 30 minutes as needed to maintain the activated clotting time between 250 and 300 seconds.

Quantitative Angiography

Coronary angiography was performed immediately before and after atherectomy with a Softip 9F guiding catheter (Schneider, Minneapolis, Minnesota). Quantitative analysis of the single most stenotic view was performed with electronic calipers (Digital Caliper System, Sandhill Scientific, Littleton, Colorado), using the 9F guiding catheter as a reference object. Prior studies have demonstrated that such electronic caliper measurements are highly reproducible and correlate well with digital image analysis.

Tissue Analysis

In 19 lesions (17 patients), atherectomy tissue specimens were removed from the device and placed on a Telfa pad to blot adherent fluid. These specimens were then transferred immediately to preweighed 1.5 mL polypropylene tubes containing 1 mL normal saline. Care was taken to deposit the tissue on the dry wall of the polypropylene tube rather than dipping the forceps into the saline solution to avoid removal of small amounts of fluid that might invalidate subsequent weights. The tubes were then sealed with air-tight caps to prevent evaporation, and the tissue specimens were shaken to the bottom of the tube. The tubes containing the specimens were then weighed to the nearest 0.1 mg with an analytical balance (Mettler), with total specimen weight calculated by subtraction of the baseline tube weight.

All removed tissue was fixed in 10% buffered formalin solution. Formalin-fixed specimens were embedded in paraffin, were cut into 6 μm sections, and stained with hematoxylin and eosin, Masson's trichrome, and elastic-van Gieson. Light microscopy was performed, and tissue specimens were evaluated by one of the authors (S.J.S.) for the presence or absence of atherosclerotic plaque, intimal proliferation, media, and adventitia.

Follow-up

Follow-up was performed by clinic visit or telephone contact. Per protocol, repeat angiography was recommended to all patients at 6 months, or earlier if symptoms recurred. Angiographic restenosis was considered to be present if the diameter stenosis at follow-up was 60% or more using the quantitative angiographic technique described.

Statistics

Data are presented as mean±SD. Student's t test was performed for comparison of data before and immediately after atherectomy. A p value of less than 0.05 was considered statistically significant. Freedom from restenosis was analyzed by lesion using standard life-table techniques where recurrent angina, angiographic restenosis, repeat atherectomy, repeat percutaneous transluminal coronary angioplasty, or coronary artery bypass graft surgery were considered events.

Results

Acute Results

Atherectomy was successful in 67 of 76 lesions (88%). In the remaining nine lesions (12%), unsuccessful atherectomy resulted from failure to cross the lesion with the rigid atherectomy device in seven patients (two circumflex, two vein graft, and three left anterior descending lesions) due to extreme tortuosity or calcification of the vessel proximal to the target lesion, and from an unsatisfactory atherectomy result in one ostial graft lesion. All eight such lesions were then treated successfully by conventional balloon dilatation. One patient developed dissection of the proximal left anterior descending artery during atherectomy of a midartery lesion. Given the extensive nature of this dissection, emergency bypass was performed even though there was no evidence of acute ischemia.

The procedure time (from arterial puncture to completion) for atherectomy (77±23 minutes) was similar to that for one-vessel percutaneous transluminal coronary angioplasty (78±38 minutes) performed by the principal operators (D.S.B. and R.D.S.) during the study period, but atherectomy procedures used a greater volume of contrast agent than did one-vessel angioplasty procedures (269±82 versus 205±87 ml, p<0.01).

Lesion Morphology and Quantitative Angiography

After successful atherectomy in 67 lesions, there was a smooth lumen in 59 lesions, mild focal dissec-
tion in three lesions, and minor irregularities of the vessel wall in five lesions due to small fragments of nonretrievable plaque or mural thrombus (Figure 2). Diameter stenosis decreased from 80±11% to 5±15%. Absolute vessel lumen diameter increased from 0.6±0.4 to 2.9±0.6 mm (both p<0.01) compared with the 3.1±0.7-mm average diameter of the adjacent reference segments (Figure 3).

The final atherectomy device was 6F in 39 and 7F in 28 of the successfully atherectomized lesions. Although the residual diameter stenosis after atherectomy was similar for the 6F (5±15%) and 7F (5±16% p=NS) devices, the 7F device produced a larger absolute lumen diameter than did the 6F device (3.7±0.6 versus 2.6±0.4 mm, respectively).

Complications

One or more of the following complications occurred in six of the 67 patients (9%). There was one proximal dissection that required emergency bypass surgery (1.5%). Although there were no Q wave myocardial infarctions, non-Q wave myocardial infarction occurred in three patients as the result of side-branch occlusion, air embolism, or vein graft plaque embolism (one patient each). Vascular injury requiring surgical repair of the femoral catheter site occurred in two patients (3.0%).

Follow-up

Follow-up was available for all patients discharged from the hospital after successful atherectomy. At
latest follow-up, (average 11.1±3.3 months), 18 patients had developed recurrent angina an average of 3.3±1.3 months after atherectomy due to restenosis of 19 lesions, yielding a per-lesion restenosis rate of 30% by the life-table method (Figure 4, top). Recurrent symptoms were managed by successful repeat atherectomy (four patients), percutaneous transluminal coronary angioplasty (five patients), intracoronary stent placement (one patient), bypass surgery (five patients), and medical therapy (three patients, including one with angiographically confirmed restenosis who died at home while awaiting bypass surgery).

Repeat angiography (Figure 4, bottom) was performed in 46 patients (52 lesions) 5.5±1.9 months after atherectomy, representing 78% of the 60 patients (67 lesions) with initially successful atherectomy. Angiographic restenosis (Figure 2) was confirmed (79±9%) in all 16 patients (17 lesions) who underwent repeat angiography for evaluation of recurrent symptoms and in one of the 30 patients (35 lesions) who underwent routine protocol-mandated restudy in the absence of symptoms. Among lesions without restenosis (Figure 5), the diameter stenosis at follow-up was 27±12%, which corresponded to a reduction in absolute vessel diameter from 3.1±0.6 mm immediately after atherectomy to 2.2±0.6 mm at follow-up. The percent diameter immediately after successful atherectomy was similar in lesions with (8±14%) and without (4±16%, p=NS) subsequent restenosis.

**Tissue Analysis**

A mean of 11.6±6 specimens were removed from each lesion at the time of atherectomy. In the 19 lesions so studied, the average weight of removed tissue was 18.5 mg (range, 5.8–45.1 mg) per lesion. These lesions appeared to be representative of our overall atherectomy experience in terms of clinical, angiographic, and histological features.

Samples from 73 lesions (67 successful atherectomies, two unsuccessful procedures that required postatherectomy percutaneous transluminal coronary angioplasty or surgery, and four repeat procedures performed for postatherectomy restenosis) were analyzed by light microscopy. Tissue samples included atherosclerotic plaque in 69 specimens (94%), media in 49 specimens (67%), and adventitia in 20 specimens (27%) (Figure 6). The incidence of recovering these components was similar for primary and secondary lesions. Despite recovery of deep wall components, there were no acute clinical sequelae. However, a focal coronary aneurysm was detected in the 6-month angiogram in one patient (who had media but not adventitia on histological study). Intimal proliferation was present in 49 of 73 vessels, including 37 of 38 secondary lesions (97%) (prior percutaneous transluminal coronary angioplasty in 30, prior atherectomy in four, prior laser balloon angioplasty in two, and prior stent in one) versus 12 of 36 primary lesions (33%) (p<0.01) (Figure 7).

**Discussion**

In recent years, several new interventional devices (e.g., stents, lasers, atherectomy catheters) have been developed to address the remaining limitations of conventional balloon angioplasty. Preliminary reports of acute results have been encouraging, but follow-up data are not yet sufficient to evaluate long-term efficacy.

**Acute Results**

Coronary atherectomy provides excellent immediate angiographic results and is unusually free of the intraluminal haziness and intimal flaps or dissection seen in as many as 40% of lesions after conventional balloon angioplasty. Angiographic evidence of dissection after atherectomy was seen in only 4.5% of lesions studied in the present study. This is similar to
FIGURE 5. Photomicrograph of atherectomy of unfavorable native coronary lesion. Left coronary angiogram in left anterior oblique cranial view (upper left panel) and in lateral view (lower left panel) showing eccentric, ulcerated restenosis plaque in proximal left anterior descending coronary artery (84% stenosis). Angiography immediately after atherectomy (middle panels) shows a smooth lumen (residual stenosis, 0%). Lumen was widely patent (16% stenosis) at routine follow-up angiography 6 months later (right panels).

FIGURE 6. Photomicrographs of retrieval of deep tissue layers during coronary atherectomy. Atherectomy sample taken from a 61-year-old man with class IV angina and a subtotal, eccentric, ulcerated stenosis in left anterior descending coronary artery. Intima (top), media, and adventitia (bottom) were identified (original magnification, ×6.3). A: Hematoxylin and eosin stain; B: Masson-trichrome stain; C: van-Gieson stain for elastic tissue.
peripheral atherectomy; Simpson et al reported dissection in only 2.2% of 136 stenoses compared with 50% of lesions treated by conventional angioplasty. Moreover, the 5% average residual stenosis after atherectomy was substantially less than the 32–43% stenosis rate achieved after conventional angioplasty. Similar excellent immediate results have been reported by other investigators. Not all lesions, however, are approachable. Most lesions (that is, those in tortuous, heavily calcified, or smaller [<2.5 mm] vessels) would still be more easily treated by conventional angioplasty rather than by the current rigid atherectomy device.

Safety

Only one patient (1.4%) in the present study required emergency bypass surgery, with no procedural deaths or Q wave myocardial infarctions. Other complications included non-Q wave infarction in three patients (4.5%) and significant femoral arterial injury in two (3.0%) patients, possibly relating to the large (11F) size of the arterial sheath. We now avoid performing atherectomy in patients who have significant peripheral vascular disease and evaluate contrast flow around the sheath at the end of each procedure. These complications appear comparable to the observed incidence of death (0.2%), Q wave infarction (3.5%), and emergency bypass (2.9%) observed among patients with one-vessel disease treated with conventional balloon angioplasty in the 1985–1986 National Heart, Lung, and Blood Institute Registry although larger numbers of patients and perhaps a trial comparing the two approaches will be needed to access the relative safety issue.

Restenosis

It was hoped that coronary atherectomy would significantly reduce the incidence of restenosis by debulking the lesion and leaving a larger, smoother lumen than conventional balloon angioplasty, despite the fact that atherectomy exposes deep layers of the arterial wall. It is clear from our data, however, that restenosis
after coronary atherectomy still occurs in 30% of lesions according to 6-month life-table analysis. The incidence of restenosis tended to be lower in patients undergoing primary rather than secondary atherectomy performed for postangioplasty restenosis (20% versus 40%, *p*=NS), but the restenosis rates of atherectomy and angioplasty will still need to be compared directly in a larger, randomized trial to demonstrate any net efficacy in the prevention of restenosis.

Histological Observations

The application of coronary atherectomy to patients with coronary artery disease provides a unique opportunity to study the histology of atherosclerosis and allows several interesting observations. Many studies have suggested that restenosis is the result of focal intimal proliferation at the dilatation site.\textsuperscript{36-40} In fact, intimal hyperplasia was identified in 97% of restenotic lesions, including those of patients who had undergone prior percutaneous transluminal coronary angioplasty (30 patients), atherectomy (four patients), laser balloon angioplasty (two patients), and stent placement (one patient). Our current data thus confirm the association between restenosis and intimal hyperplasia.

Histologically similar intimal hyperplasia, however, was observed in 33% of virgin lesions (Figure 7). Such intimal hyperplasia may represent a new mechanism by which lesion progression may occur in patients with unstable or new onset angina, possibly as a consequence of platelet or smooth muscle cell secretion of mitogenic factors in response to spontaneous ulceration or rupture.\textsuperscript{41}

Potential Mechanisms of Atherectomy

While both coronary atherectomy and coronary angioplasty enlarge the coronary lumen, there are several important differences between the two techniques. Balloon angioplasty cracks and disrupts atherosclerotic plaque and separates plaque from the media to allow stretching of the vessel wall.\textsuperscript{34,42,43} McBride et al referred to these changes as the "controlled injury" of successful balloon angioplasty.\textsuperscript{44}

In contrast, the fundamental mechanism of coronary atherectomy was conceived to be excision of atherosclerotic plaque. By geometric calculation, complete atherectomy of an occluded vessel segment 3.0 mm in diameter and 10 mm in length should result in removal of approximately 70 mg tissue (assuming a plaque specific gravity of 1.0). That the average weight of removed tissue in our series was only 18.5 mg (with angiographic and clinical success after removal of as little as 5.8 mg tissue) suggests that part of the improvement seen with coronary atherectomy is due to mechanical dilatation rather than to tissue removal alone. This might occur by Dottering the lesion during passage of the device or by inflation of the atherectomy catheter balloon. Effective dilatation at the low (20–30 psi) balloon inflation pressures used would require a marked increase in radial compliance of the vessel wall, which might occur in an eccentric lesion or after excision of plaque and media had resulted in marked thinning of the vessel wall. The difference between "pure" atherectomy and the combination of partial atherectomy plus mechanical dilatation would not be evident angiographically, but preliminary reports of intravascular ultrasound performed after successful peripheral atherectomy support the concept that significant luminal plaque remains despite an excellent angiographic result.\textsuperscript{45}

Removal of media and occasionally partial thickness strips of adventitia could theoretically lead to acute perforation or late aneurysm formation. To date, repeat angiography has revealed focal aneurysm formation in one of our patients in whom media but not adventitia was identified on histology, but late aneurysm formation is not specific for atherectomy. It has also been reported after conventional percutaneous transluminal coronary angioplasty with one report suggesting an incidence as high as 5% at 6 months.\textsuperscript{46,47} Other investigators have recently described a similarly high incidence of retrieving deep arterial wall components during coronary atherectomy, generally without acute loss of vessel integrity,\textsuperscript{48} although vessel perforation has now been reported in five cases (0.5%) in the multicenter registry.\textsuperscript{49}

Limitations

There are several limitations of this study. First, it is an uncontrolled, nonrandomized observational study limited to the subset of patients with ischemic heart disease whose anatomies are suitable for coronary atherectomy. Second, it is based on early experience with prototype atherectomy catheters. Operator experience with technically superior catheter designs may further improve the immediate and long-term outcome and may decrease the incidence of complications and late restenosis. Third, the contribution of mechanical dilatation will need to be evaluated further by analysis of tissue weights and lumen volumes in large numbers of patients, in other laboratories, and with other techniques such as luminal ultrasound. Preliminary data from one other center (J.B. Simpson and T. Hinohara, personal communication), however, show a similar removal of tissue (roughly 23 mg) during more than 80 successful coronary atherectomy procedures. Fourth, angiographic follow-up has been performed in only 78% of patients. More complete or later (that is, 1 year) angiographic follow-up or use of alternative definitions might alter the observed incidence of restenosis.

Conclusion

Excision of atherosclerotic plaque from coronary arteries with a directional atherectomy catheter appears to provide a safe, effective, and reliable treatment for selected coronary artery stenoses. The immediate angiographic results and incidence of serious complications compare favorably with conventional balloon angioplasty. Early follow-up data, however, show that restenosis still occurs. Thus, demonstration
of a long-term benefit relative to conventional percutaneous transluminal coronary angioplasty can be established only by a randomized clinical trial.

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References

**KEY WORDS** • atherectomy • lesions • restenoses
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