Final Results of the Balloon vs Optimal Atherectomy Trial (BOAT)

Donald S. Baim, MD; Donald E. Cutlip, MD; Samin K. Sharma, MD; Kalon K.L. Ho, MD, MSc; Richard Fortuna, MD; Theodore L. Schreiber, MD; Robert L. Feldman, MD; Jacob Shani, MD; Cynthia Senerchia, RN, MS; Yan Zhang, MS; Alexandra J. Lansky, MD; Jeffrey J. Popma, MD; Richard E. Kuntz, MD, MSc; for the BOAT Investigators

Background—Previous directional coronary atherectomy (DCA) trials have shown no significant reduction in angiographic restenosis, more in-hospital complications, and higher 1-year mortality than conventional balloon angioplasty (percutaneous transluminal coronary angioplasty [PTCA]). DCA, however, has subsequently evolved toward a more “optimal” technique (larger devices, more extensive tissue removal, and routine postdilation to obtain diameter stenosis <20%).

Methods and Results—The Balloon vs Optimal Atherectomy Trial (BOAT) was conducted to evaluate whether optimal DCA provides short- and long-term benefits compared with balloon angioplasty. One thousand patients with single de novo, native vessel lesions were randomized to either DCA or PTCA at 37 participating centers. Lesion success was obtained in 99% versus 97% (P=.02) of patients to a final residual diameter stenosis of 15% versus 28% (P<.0001) for DCA and PTCA, respectively, the latter including stents in 9.3% of the patients. There was no increase in major complications (death, Q-wave myocardial infarction, or emergent coronary artery bypass graft surgery [2.8% versus 3.3%]), although creatine kinase–MB >3× normal was more common with DCA (16% versus 6%; P<.0001). Angiographic restudy (in 79.6% of eligible patients at 7.2±2.6 [median, 6.9] months) showed a significant reduction in the prespecified primary end point of angiographic restenosis by DCA (31.4% versus 39.8%; P=.016). Clinical follow-up to 1 year showed nonsignificant 13% to 17% reductions in the DCA arm of the study for mortality rate (0.6% versus 1.6%; P=.14), target-vessel revascularization (17.1% versus 19.7%; P=.33), target-site revascularization (15.3% versus 18.3%; P=.23), and target-vessel failure (death, Q-wave myocardial infarction, or target-vessel revascularization, 21.1% versus 24.8%; P=.17).

Conclusions—Optimal DCA provides significantly higher short-term success, lower residual stenosis, and lower angiographic restenosis than conventional PTCA, despite failing to reach statistical significance for reducing late clinical events compared with PTCA with stent backup. (Circulation. 1998;97:322-331.)

Key Words: angioplasty • atherectomy • restenosis • coronary intervention • trials

Directional coronary atherectomy was developed by John Simpson in the late 1980s as a way to excise (rather than simply displace) obstructive coronary atheroma, providing an alternative to conventional balloon angioplasty. After approval was obtained from the Food and Drug Administration in October 1990, two randomized trials compared DCA with conventional balloon angioplasty for the treatment of de novo native coronary lesions (CAVEAT1 and CCAT2). The failure of these randomized trials to show significant benefit of DCA over conventional balloon angioplasty has generally been interpreted as a condemnation of this new technology.3

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Selected Abbreviations and Acronyms

BOAT = Balloon vs Optimal Atherectomy Trial  
CABG = coronary artery bypass grafting  
CAVEAT = Coronary Angioplasty Versus Excisional Atherectomy Trial  
CCAT = Canadian Coronary Atherectomy Trial  
CPK = creatine phosphokinase  
DCA = directional coronary atherectomy  
LAD = left anterior descending coronary artery  
MI = myocardial infarction  
NHLBI = National Heart, Lung, and Blood Institute  
OARS = Optimal Atherectomy Restenosis Study  
PTCA = percutaneous transluminal coronary angioplasty  
TIMI = Thrombolysis In Myocardial Infarction  
TSR = target-site revascularization  
TVF = target- vessel failure  
TVR = target- vessel revascularization

balloon postdilation to obtain <20% short-term posttreatment residual stenosis), subsequent investigations have been undertaken. OARS was a four-center, 200-patient registry in which serial angiographic and intravascular ultrasound measurements were obtained during DCA procedures and at 6-month follow-up, described elsewhere.7 BOAT, the results of which are described in this report, was a 1000-patient randomized clinical trial comparing the optimal DCA technique with conventional balloon angioplasty, with a primary end point of reduction in late (6-month) angiographic restenosis.

Methods

Site Selection and Training

Because BOAT was a study of a technique of use (not just which device was used), special care was taken to familiarize the BOAT operators with the optimal atherectomy technique. As in the earlier OARS registry, the main principles were (1) to use 7F cutters as the final device in the study vessels, (2) to remove as much tissue as considered safe by the operator, (3) to complete the procedure by postdilation with a full-sized conventional angioplasty balloon (balloon:artery ratio of 1.0 to 1.2), and (4) to obtain a final residual stenosis <20% whenever possible.9 Use of intravascular ultrasound was allowed but neither encouraged nor required (12.9% of DCA cases). Each operator at the 37 participating centers (see “Appendix”) was required to perform five “pilot” procedures according to these principles and to submit the procedural films to the angiographic core laboratory for review before beginning randomization in the BOAT study. The short-term clinical and angiographic results of this 192-patient pilot phase have been reported previously.5

Study Design

BOAT was a randomized clinical trial comparing the optimal directional atherectomy technique with conventional balloon angioplasty. Inclusion criteria included a focal, noncalcified, de novo lesion in a native coronary artery of adequate caliber ($\geq$3.0 mm by visual estimate to allow the use of a 7F cutter as the final atherectomy device) in a patient with stable or unstable angina at least 5 days after MI. Exclusion criteria included bifurcated lesion, multiple lesion treatment, stroke within 3 months, and peripheral vascular disease that precluded use of a 10F arterial sheath.

Eligible patients were invited to participate in the trial, and informed consent was obtained under a protocol approved by the institutional review board at each participating center. Patients were then assigned randomly (with equal probability of DCA or PTCA, stratified by clinical site and history of diabetes mellitus). Detailed case report forms concerning baseline demographic and clinical data, procedural details, and in-hospital outcome (including routine ascertainment of CPK and CPK-MB before treatment, 4 to 6 hours after the procedure, and at the earlier of hospital discharge or 24 hours after the procedure; further determinations were required if either CPK or CPK-MB was elevated) were completed by the clinical coordinator at each site and submitted to the data coordinating center (the Cardiovascular Data Analysis Center, Boston, Mass).

All cineangiograms were forwarded to the Washington Hospital Center Angiographic Core Laboratory for analysis. Baseline and postprocedural morphology was recorded by use of standard criteria.9 Selected cine frames that demonstrated the stenosis most clearly were digitized and analyzed by observers who were blinded to the treatment strategy. Reference and minimal lumen diameters were determined with the use of the cardiovascular measurement system (CMS) using the contrast-filled injection catheter as the calibration standard.10 All ECGs were reviewed by the ECG core laboratory (Beth Israel Deaconess Medical Center, Boston, Mass) for development of new pathological Q waves or persistent ST segment or T-wave abnormalities by electrocardiographers blinded to treatment assignment and clinical events.

Clinical follow-up was obtained at 6 weeks, 6 months, 9 months, and 1 year for the occurrence of an adverse cardiac event (death, MI, or any repeat revascularization procedure). The potential relationships of such complications and repeat revascularizations to the index randomized treatment strategy and target site were adjudicated by a clinical events committee blinded to treatment assignment.

Angiographic follow-up was obtained routinely at 6 months, unless earlier follow-up was required clinically and demonstrated restenosis ($\geq$50% stenosis by core laboratory analysis) of the treated site, or it was performed at least 4 months after the index treatment. The only patients exempted from angiographic follow-up were those undergoing preprocedural CABG or who died <6 months after the index procedure. Renarrowing of the target site during the first 14 days after the procedure was considered subacute closure rather than restenosis, and these patients remained eligible for angiographic follow-up (unless treated with bypass surgery).

The prespecified primary end point was angiographic restenosis (late diameter stenosis $\geq$50% by core laboratory assessment). Secondary end points included measures of short-term procedural success and safety, clinical restenosis surrogates, and clinical status at 1 year. Deaths were classified as acute ($\leq$30 days after the procedure) or late; all deaths were considered cardiac unless clearly attributable to a noncardiac cause. Documentation by the ECG core laboratory of new, pathological Q waves in two or more contiguous leads associated with any elevation of CPK-MB was required for the diagnosis of a Q-wave MI. Non-Q-wave MIs were determined with the use of a ratio of peak periprocedural CPK-MB to the upper limit of normal for each clinical institution. The need for CABG or use of a nonrandomized bailout device (stenting in either arm of the study or use of DCA in the PTCA arm) was judged as emergent if it was performed for overt or threatened abrupt closure. Overt closure was defined as persistently reduced coronary flow (TIMI grade 0 or 1) due to mechanical complication that led to emergency CABG or use of a bailout device or resulted in a major complication (death, Q-wave MI, or large non-Q-wave MI). Threatened abrupt closure was diagnosed by the presence of an NHLBI grade B dissection and $\geq$50% diameter stenosis or a dissection of NHLBI grade C or worse. Repeat revascularizations of restenotic target sites ($\geq$50% diameter stenosis by core laboratory analysis >14 days after the index treatment) in patients with recurrent angina and/or positive functional ischemia studies or treatment of target lesions with $\geq$70% diameter stenosis (by core laboratory) were considered to represent clinically driven TSRs. Similar clinical criteria were used to adjudicate the clinical need for TVR, which included treatment of the target site or lesions elsewhere in the same major epicardial coronary artery or its branches. A composite end point of TVF was defined as clinically driven TVR or the occurrence of death or Q-wave MI not clearly attributable to another major epicardial coronary artery.
TABLE 1. Baseline Clinical Characteristics

<table>
<thead>
<tr>
<th></th>
<th>DCA (n=497)</th>
<th>PTCA (n=491)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number randomized</td>
<td>497</td>
<td>491</td>
</tr>
<tr>
<td>Age (mean±SD), y</td>
<td>58.4±11.0</td>
<td>58.3±9.7</td>
</tr>
<tr>
<td>Female, %</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>H/O diabetes mellitus, %</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>H/O hypertension, %</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>H/O cigarette smoking within 1 year, %</td>
<td>35</td>
<td>36</td>
</tr>
<tr>
<td>H/O dyslipidemia, %</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>Family H/O premature CAD, %</td>
<td>36</td>
<td>39</td>
</tr>
<tr>
<td>Prior PTCA of target vessel, %</td>
<td>0.6</td>
<td>2</td>
</tr>
<tr>
<td>Prior CABG, %</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Prior MI, %</td>
<td>42</td>
<td>39</td>
</tr>
<tr>
<td>Within 2 months, %</td>
<td>32</td>
<td>27</td>
</tr>
<tr>
<td>LVEF (mean±SD), %</td>
<td>58±12</td>
<td>59±11</td>
</tr>
</tbody>
</table>

H/O indicates history of; CAD, coronary artery disease; and LVEF, left ventricular ejection fraction.

Statistical Considerations

This study was designed to detect a 20% relative reduction in the primary end point of angiographic restenosis (from 40% in the PTCA arm to 30% in the DCA arm) in anticipation of an 80% angiographic follow-up. To achieve a power of 80% using a two-sided level of significance of 5%, 494 patients would need to be randomized to each treatment group; hence, the planned sample size was 1000 patients. All analyses used intent-to-treat samples. Continuous variables were examined by use of Fisher’s exact tests or Wilcoxon nonparametric tests. Binary and polychotomous variables were examined by use of log-rank test. Survival estimates were computed by use of Kaplan-Meier methods and compared by use of log-rank test. Predictors of binary restenosis were examined by use of multivariate logistic regression models. Changes in angiographic minimal lumen diameter and the loss index were analyzed by use of multivariate logistic regression models. Continuous measures are summarized as mean±SD; frequencies are displayed as counts and percentages. A two-sided value of P<.05 was required for statistical significance. All statistical analyses were performed with the use of SAS for Windows (versions 6.08 to 6.12, SAS Institute).

Results

Patient Characteristics

Recruitment lasted from May 1994 through November 1995, resulting in the enrollment and randomization of 1000 patients. Deregistration occurred for 11 patients (8 in the DCA and 3 in the PTCA arm of the study) owing to documentation of lesion diameter stenosis <50% before treatment (n=7), withdrawal of patient consent (n=2), participation in another trial (n=1), or need to treat a second lesion (n=1). The study population thus consisted of 989 patients (497 randomized to DCA and 492 to PTCA). Baseline demographic and clinical data are shown in Table 1. Baseline angiographic characteristics are shown in Table 2.

Procedure Performance

Directional atherectomy was performed using 19.5±11.8 cuts during 2.5±1.7 introductions of a device. In 95% of procedures, final device size was 7F with a 6F GTO cutter used in the remaining 5% of procedures. Balloon postdilation using a balloon:artery ratio of 1.05±0.20 was used in 392 (81%) of the 486 lesions undergoing DCA, with no further treatment beyond DCA in 94 lesions. Adjunctive balloon treatment was used for abrupt closure in 9 patients (1.8%), threatened abrupt closure in 24 (4.8%), unsuccessful DCA procedure (>50% residual stenosis) in 8 (1.6%), suboptimal DCA (residual stenosis 20% to 50%) in 151 (30.4%), and further improvement of optimal DCA (<20% residual stenosis) in 197 (39.6%). In the conventional angioplasty arm of the study, the balloon:artery ratio was 1.03±0.12 (as determined by the core laboratory).

Short-term Results

Reference vessel diameter (3.25 versus 3.20 mm) and pretreatment minimal lumen diameter (1.07 versus 1.04 mm) were identical in the DCA and PTCA arms. Lesion success (post-treatment diameter stenosis <50%) was obtained in 99% of DCA and 97% of PTCA patients (P=.02). This entailed the use of an unplanned device in 26 DCA patients (5.2%; all stents) and 60 PTCA patients (12.2%, including 46 [9.3%] stents and 14 [2.9%] DCA) (P<.0001). Unplanned device use was blindly adjudicated by the clinical events committee as being performed on an emergency basis (ie, to avoid emergency surgery) in 4.1% of DCA and 9.3% of PTCA patients; the remaining uses were presumably driven by the operator's desire to improve what was perceived as a suboptimal result of the assigned therapy. Procedure success (residual stenosis <50%, without death, Q-wave MI, emergent CABG, or emergency surgery) in 4.1% of DCA and 9.3% of PTCA patients; the remaining uses were presumably driven by the operator's desire to improve what was perceived as a suboptimal result of the assigned therapy. Procedure success (residual stenosis <50%, without death, Q-wave MI, emergent CABG, or emergency use of a bailout device) was obtained in 93% of DCA and 87% of PTCA patients (P=.001).

Angiographic core laboratory analysis showed a significantly larger posttreatment lumen diameter (2.82±0.45 versus 2.33±0.49 mm; P<.0001) and a significantly lower posttreatment residual diameter stenosis (14.7±13.1% versus 28.1±13.0%; P<.0001) in patients assigned to DCA (Fig 1 top and bottom). In the DCA patients who underwent postdilation, most of this benefit was obtained by DCA (post-DCA stenosis 13.1% versus 17.1%, although further improvement was provided by balloon postdilation (reduction in diameter stenosis to 14.7±11.0%). This is compared with a residual diameter stenosis of 11.9±11.5% in the 94 lesions for which no postdilation was performed after what was perceived as an
optimal result of stand-alone DCA. The goal of achieving a final diameter stenosis <20% by qualitative coronary angiography was obtained in 68% of patients assigned to DCA versus 26% of patients assigned to PTCA (P < .0001). Qualitative analysis of the final angiogram also showed fewer total dissections (6% versus 14%; P = .0001) and fewer major dissections (NHLBI grades C through F, 2% versus 9%; P < .0001) in the DCA arm than in the PTCA arm, respectively. There was no difference in residual diameter stenosis in patients undergoing DCA with or without the aid of intravascular ultrasound (14.4 ± 17.2% versus 14.7 ± 12.4%).

Short-term Complications
The incidence of major complications is shown in Table 3. There was no significant difference in the incidence of death, Q-wave MI, or emergency surgery between the DCA and the PTCA arms (2.8% versus 3.3%; P = .72). Perforation was seen in 1.4% of patients in the DCA arm and led to clinical sequelae in 0.8% (transient closure in one patient managed by emergent stenting, persistent closure of the distal right coronary artery in one patient, and two emergent surgeries including one for clinical pericardial tamponade).

BOAT confirmed earlier studies showing a greater incidence of elevation of cardiac enzymes after otherwise successful DCA procedures. Total CPK values were available for 97% of DCA and 97% of PTCA patients (CPK-MB data were available for 85% and 78% of patients, respectively) and showed elevation of CPK-MB above normal in 34% of DCA and 14% of PTCA patients (Fig 2). Elevation >3× normal was seen in 16% of DCA and 6% of PTCA patients, and elevation >5× normal was seen in 9% of DCA and 4% of PTCA patients. The incidence of “larger” MIs ( predefined as Q-wave MI, CPK-MB >8× normal, or total CPK >3× normal with missing CPK-MB data) was significantly higher for DCA than PTCA patients (6% versus 2%; P = .002). These larger MIs were associated with angiographically evident complications in 38 (90.5%) of 42 patients, including 19 (45%) with in-laboratory abrupt closure or subacute closure within 24 hours, 12 (29%) with dissections of NHLBI grade C or worse, 10 (24%) with side-branch occlusions, 5 (12%) with “no reflow,” and 4 (10%) with distal embolization or thrombus.

Angiographic Restenosis
A total of 9 patients in the DCA arm and 19 patients in the PTCA arm were ineligible for follow-up angiography due to periprocedural CABG (6 and 11 patients, respectively), death before scheduled follow-up (2 and 5 patients, respectively), or repeat revascularization within 3 months without evidence of restenosis (1 and 3 patients, respectively). Angiographic follow-up was obtained in 765 patients (79.6% of those eligible).

Figure 1. Baseline and acute angiographic results. Top, Cumulative distribution of reference vessel diameter and minimal lumen diameter (MLD) at baseline (Pre) and after final treatment (Post). Reference vessel diameter and preprocedural diameter were not different, whereas postprocedural diameters were significantly larger for DCA versus PTCA. Bottom, Cumulative distribution of percent diameter stenosis at baseline and after final treatment. Postprocedural diameter stenosis was less and significantly more patients achieved the “optimal” result (diameter stenosis <20%) in the DCA arm of the study (68% versus 26% in the PTCA arm).

Figure 2. Periprocedural myocardial creatine kinase (CK-MB). Cumulative distribution of peak postprocedural CK-MB ratios (for each multiple of upper limit of laboratory normal, the percent of patients is shown whose peak CK-MB ratio exceeded that value). Any elevation of CK-MB (CK-MB ratio >1) and elevations of CK-MB >3× normal were each more frequent after DCA than after PTCA.

Table 3. Major Complications (In-Hospital)

<table>
<thead>
<tr>
<th>Complication</th>
<th>DCA (n=497)</th>
<th>PTCA (n=492)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death, %</td>
<td>0.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Q-wave MI, %</td>
<td>2.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Emergent bypass surgery, %</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Any major complication, %</td>
<td>2.8</td>
<td>3.3</td>
</tr>
</tbody>
</table>
including 401 patients (82%) in the DCA arm and 364 patients (77%) in the PTCA arm of the study.

The results for follow-up lumen diameter and diameter stenosis are shown in Fig 3, top and bottom. Late lumen diameter was significantly larger (1.86 ± 0.71 versus 1.69 ± 0.68 mm; \( P = .002 \)) and late diameter stenosis significantly lower (40.1 ± 20.8% versus 45.6 ± 20.2%; \( P = .002 \)) in the DCA arm. Restenosis (defined as late diameter stenosis ≥50%), the primary end point of the trial, was significantly reduced in the DCA arm (31.4% versus 39.8%; \( P = .016 \)). Late aneurysm formation (late lumen diameter >20% above reference vessel diameter) was seen in 5.2% of DCA patients versus 2.9% of PTCA patients (\( P = .14 \)).

To examine the mechanism by which DCA provided its larger lumen diameter at angiographic follow-up, the short-term gain produced by the initial intervention and the late loss between the intervention and late follow-up were analyzed (Table 4). The short-term gain produced by DCA was significantly larger than that produced by conventional PTCA (1.76 versus 1.31 mm; \( P < .001 \)). Despite the larger late loss that followed DCA (0.96 versus 0.66 mm; \( P < .001 \)), the long-term net gain in lumen diameter produced by DCA remained greater than that produced by PTCA (0.80 versus 0.65 mm; \( P < .01 \)). The relation of late loss to short-term gain, or loss index (the slope of the regression line between short-term gain and late loss), was essentially identical for the two procedures (loss index 0.51 versus 0.49, DCA versus PTCA).

This mechanism was investigated further in a multivariate linear model of late lumen diameter and a multivariate logistic model of late restenosis. Both models identified the immediate posttreatment minimal lumen diameter as the strongest predictor of a favorable late result (\( P = .0001 \)) and identified an association of LAD lesion location with a less favorable late result (\( P = .007 \)). Once these variables were included in the model, the treatment assignment (DCA versus PTCA) was no longer a significant predictor of either the late lumen diameter or the probability of angiographic restenosis.

### Clinical Follow-up

By 1 year, there were three deaths in the DCA arm of the study (none within 30 days and three during follow-up) for a mortality rate of 1.6%. There were eight deaths (two within 30 days and six during follow-up) in the PTCA arm of the study, for a mortality rate of 1.0% (\( P = .50 \)). The circumstances of the late deaths are shown in Table 5. There was no overall relationship between the elevation of periprocedural CPK and 1-year cumulative mortality rate (1.2% in patients with CPK >1× normal, 1.0% in those with normal CPK) (Table 6).

There was no difference in the incidence of Q-wave MI during follow-up between the DCA and PTCA arms (0 versus 0.4%; \( P = .50 \)) or in the cumulative incidence of Q-wave MI at 1 year (2.0% versus 1.6%; \( P = .81 \)) (Table 7). The incidence of death or Q-wave MI during follow-up (0.6% versus 1.6%; \( P = .14 \)) and the cumulative incidence of death or Q-wave MI at 1 year (2.6% versus 3.3%; \( P = .577 \)) were thus no higher for DCA than for PTCA.

The incidence of repeat revascularization at 1 year was similar for patients assigned to initial DCA versus initial PTCA (25.4% versus 28.1%; \( P = .65 \)), which included CABG (2.8% versus 4.7%; \( P = .13 \)) or a repeat percutaneous procedure alone (22.5% versus 23.4%; \( P = .76 \)). When the prespecified secondary end point of clinically driven repeat revascularization of the initially treated target vessel (TVR) or target site (TSR) was used, the incidence of such events was 13% to 17% lower in the cohort assigned to initial DCA (TSR, 15.3% versus 18.3%..
TABLE 5. Report of Deaths During First Year of BOAT

<table>
<thead>
<tr>
<th>Group</th>
<th>Type</th>
<th>Days</th>
<th>Clinical Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTCA</td>
<td>Cardiac</td>
<td>2</td>
<td>Successful index procedure; CPK-MB elevated to 1.2× normal; died suddenly at home.</td>
</tr>
<tr>
<td>PTCA</td>
<td>Cardiac</td>
<td>6</td>
<td>Successful index procedure; no CPK elevation; died suddenly at home.</td>
</tr>
<tr>
<td>PTCA</td>
<td>Cardiac</td>
<td>54</td>
<td>Successful index procedure; no CPK elevation; readmitted with acute MI; angiography revealed occluded target site; persistent VT; emergent bypass; died 6 days later.</td>
</tr>
<tr>
<td>PTCA</td>
<td>Cardiac</td>
<td>108</td>
<td>Successful index procedure; crossover to DCA for nonemergent indication; no postprocedure CPK values; sudden death.</td>
</tr>
<tr>
<td>PTCA</td>
<td>Cardiac</td>
<td>137</td>
<td>Successful index procedure; no CPK elevation; cardiac arrest and died 4 days after resuscitation.</td>
</tr>
<tr>
<td>PTCA</td>
<td>Cardiac</td>
<td>178</td>
<td>Successful index procedure; no CPK elevation; sudden death.</td>
</tr>
<tr>
<td>PTCA</td>
<td>Cardiac</td>
<td>222</td>
<td>Successful index procedure; no CPK elevation; TVR at 70 days; acute MI.</td>
</tr>
<tr>
<td>PTCA</td>
<td>Noncardiac</td>
<td>246</td>
<td>Successful index procedure; presented with massive upper GI bleed, shock.</td>
</tr>
<tr>
<td>DCA</td>
<td>Cardiac</td>
<td>171</td>
<td>Successful index procedure; no CPK elevation; collapsed after riding bicycle and died suddenly.</td>
</tr>
<tr>
<td>DCA</td>
<td>Cardiac</td>
<td>231</td>
<td>Successful procedure; CPK-MB elevated to 1.8× normal; died from complications of cardiac amyloidosis.</td>
</tr>
<tr>
<td>DCA</td>
<td>Noncardiac</td>
<td>244</td>
<td>Successful procedure; CPK-MB elevated to 1.2× normal; died from respiratory failure, interstitial fibrosis.</td>
</tr>
</tbody>
</table>

VT indicates ventricular tachycardia; GI, gastrointestinal.

Table 5.

TABLE 6. One-Year Mortality as Related to CPK or CPK-MB Elevation

<table>
<thead>
<tr>
<th></th>
<th>DCA (n=497)</th>
<th>PTCA (n=492)</th>
<th>Overall (n=989)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Patients</td>
<td>Deaths, (Mortality Rate)</td>
<td>Number of Patients</td>
</tr>
<tr>
<td>No CPK or CPK-MB elevation</td>
<td>310</td>
<td>1 (0.3%)</td>
<td>404</td>
</tr>
<tr>
<td>Any CPK-MB elevation</td>
<td>171</td>
<td>2 (1.2%)</td>
<td>71</td>
</tr>
<tr>
<td>CPK-MB &gt;3× normal</td>
<td>78</td>
<td>0 (0%)</td>
<td>29</td>
</tr>
<tr>
<td>CPK-MB &gt;5× normal</td>
<td>45</td>
<td>0 (0%)</td>
<td>18</td>
</tr>
<tr>
<td>CPK elevated/missing CPK-MB</td>
<td>1</td>
<td>0 (0%)</td>
<td>1</td>
</tr>
<tr>
<td>Missing CPK and CPK-MB</td>
<td>15</td>
<td>0 (0%)</td>
<td>17</td>
</tr>
</tbody>
</table>

Discussion

Early DCA Trials

The two previous randomized trials (CAVEAT 1 and CCAT 2) that compared the short- and long-term results of directional atherectomy with conventional balloon angioplasty in the treatment of focal, de novo lesions of native coronary arteries showed that DCA was able to provide a slightly larger acute lumen diameter than PTCA (2.02 versus 1.80 mm in CAVEAT and 2.34 versus 2.10 mm in CCAT), corresponding to a slightly lower residual diameter stenosis (29% versus 36% in CAVEAT and 26% versus 33% in CCAT). It was disappointing, however, that there was little reduction in subsequent angiographic restenosis rates (50% versus 57% in CAVEAT and 46% versus 43% in CCAT) and that there were no reductions in clinical restenosis (33.7% versus 35.0% in CAVEAT and 30.1% versus 30.6% in CCAT). Although there was no increase in major short-term complications of DCA compared with PTCA in CAVEAT (death, 0% versus 0.4%; Q-wave MI, 2% versus 2%; emergency CABG, 3% versus 2%), there was nearly a doubling in the incidence of “other” MIs, including asymptomatic elevations...
of CPK, in the DCA cohort. One-year mortality data revealed a higher death rate in the DCA cohort (2.2% versus 0.6%; \(P=0.035\)), putatively related to the greater short-term prevalence of non–Q-wave MI. Economic data showed greater in-hospital cost without putatively related to the greater short-term prevalence of non–Q-wave MI. Economic data showed greater in-hospital cost without putatively related to the greater short-term prevalence of non–Q-wave MI.

### Table 7. Cumulative One-Year Clinical Outcome

<table>
<thead>
<tr>
<th>End Point</th>
<th>DCA (n=497)</th>
<th>PTCA (n=492)</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death, %</td>
<td>0.6</td>
<td>1.6</td>
<td>.14</td>
</tr>
<tr>
<td>Q-wave MI, %</td>
<td>2.0</td>
<td>1.6</td>
<td>.81</td>
</tr>
<tr>
<td>TSR, %</td>
<td>15.3</td>
<td>18.3</td>
<td>.23</td>
</tr>
<tr>
<td>TVR, %</td>
<td>17.1</td>
<td>19.7</td>
<td>.33</td>
</tr>
<tr>
<td>TVF, %</td>
<td>21.1</td>
<td>24.8</td>
<td>.17</td>
</tr>
<tr>
<td>TVF or emergent bailout, %</td>
<td>23.1</td>
<td>31.1</td>
<td>.006</td>
</tr>
</tbody>
</table>

*Death, Q-wave MI, or TVR.*

Rationale for Optimal Atherectomy

After the release of the CAVEAT and CCAT data, questions were raised about whether the potential benefits of the DCA device might have been underestimated because of the way in which the DCAs were performed in these trials. The possibility was thus raised that had CAVEAT and CCAT used the alternative technique (now known as “optimal atherectomy”), the larger resulting acute lumens would have significantly reduced the incidence of subsequent restenosis compared with conventional balloon angioplasty.

The safety and efficacy of optimal atherectomy were first tested in OARS,7 a 199-patient (213 treated lesions) registry of DCA procedures performed in native vessels at four participating centers in 1994. In OARS, 7F devices were used in 95% of procedures and postdilation in 87% of procedures to obtain a final minimal lumen diameter of 3.16 mm (7% diameter stenosis). Late angiographic follow-up in 83% of patients showed a restenosis rate (>50% by definition) of 29.6%. Clinical follow-up at 1 year showed one cardiac death (0.5%), no Q-wave MI, and a TSR rate of 17.8%.

To fully test the optimal atherectomy strategy, however, it was important to show that the technique could be applied by a more diverse set of centers and operators and that it could show a benefit compared with conventional balloon angioplasty in a randomized clinical trial format, which provided the impetus for BOAT. Before randomization was begun, each operator was encouraged to perform five consecutive pilot cases using the prescribed atherectomy strategy, leading to the 192-case pilot study reported recently.6

On the basis of these favorable preliminary studies, the full BOAT trial (reported herein) was begun in May 1994 at 37 centers in the United States, Canada, and Europe. The 1000th patient was enrolled in November 1995. As the result of similar inclusion criteria, the baseline demographic and angiographic features of BOAT are generally comparable to those in CAVEAT.

BOAT patients assigned to the DCA arm of the study had a higher short-term lesion success rate (residual stenosis <50%, 99% versus 97%; \(P=0.02\)) and procedural success rate (lesion success without major complication, 93% versus 87%; \(P=0.001\)) than those assigned to conventional PTCA. This reflected the more common use of other bailout procedures in the PTCA arm (12% versus 5% in the DCA arm; \(P<0.0001\)), which included stent placement in 9% of PTCA and 5% of DCA patients. Bailout procedures were adjudicated by the clinical events committee as having been done to avoid emergency surgery in 4.1% of DCA patients versus 9.3% of PTCA patients. The quality of procedural success was also greater in the DCA arm, with a larger posttreatment lumen (2.82 versus 2.33 mm; \(P<0.0001\)), a lower posttreatment residual diameter stenosis (14.7% versus 28.1%; \(P<0.0001\)), and a lower incidence of dissection at the treatment site (final dissection grade C or greater, 2% versus 9%; \(P<0.0001\)). In total, 68% of the DCA patients (but only 26% of the PTCA patients) met the prespecified goal of a residual diameter stenosis <20% by qualitative coronary angiography. The short-term result was not enhanced in the 12.9% of DCA patients with intravascular ultrasound (diameter stenosis of 14.4% as opposed to 14.7% in patients undergoing DCA without intravascular ultrasound).

![Figure 4. Event-free survival during follow-up. Top, Kaplan-Meier estimate of overall survival, showing a trend (\(P=0.13\)) toward improved survival in the cohort randomly assigned to DCA. Middle, Kaplan-Meier estimate of freedom from death or Q-wave MI at 1 year, showing no difference between DCA and PTCA. Bottom, Kaplan-Meier estimate of freedom from TVF (defined as death, Q-wave MI, or TVR). At 1 year, the observed difference in favor of DCA was not statistically significant.](http://circ.ahajournals.org/doi/abs/10.1161/01.CIR.101.6.699)
The net benefit of this higher short-term success and larger acute lumen diameter was obtained without increasing short-term complications. The incidence of death (0% versus 0.4%; \( P = 0.25 \)), Q-wave MI (2.0% versus 1.2%; \( P = 0.45 \)), emergency surgery (1.0% versus 2.0%; \( P = 0.21 \)), or any of these major complications (2.8% versus 3.3%; \( P = 0.60 \)) was no greater for patients assigned to DCA than for those assigned to PTCA. The only complication that was significantly greater in the DCA arm was the incidence of CPK-MB elevations after otherwise successful procedures. It has been recognized that such elevations of CPK-MB are common (they occur in up to 30% of patients) after DCA and other atherectomy procedures,\(^ {1,16} \) but they are typically of low order (<3× normal). The systematic collection of CPK and CPK-MB data for each patient in BOAT showed the expected higher incidence of any CPK elevation with DCA (34% versus 14%; \( P < 0.0001 \)) and CPK-MB elevation >3× normal (16% versus 6%; \( P < 0.0001 \)), as had been reported in the randomized CAVEAT study (19% versus 8%).

In the prior CAVEAT study, patients who were randomized to DCA had a higher 1-year mortality rate than those randomized to PTCA (2.2% versus 0.6%; \( P = 0.035 \)),\(^ {13} \) which along with other retrospective studies of periprocedural creatine kinase elevation\(^ {15,20} \) has raised concern about potential late deleterious consequences of DCA. The BOAT data differ from CAVEAT, however, in that the mortality rate at 1 year was actually somewhat lower in the DCA arm (0.6% versus 1.6%), owing both to lower 30-day mortality rates (0.0% versus 0.4%) and lower late-term mortality rates (0.6% versus 1.2%). There is thus no suggestion from BOAT that the "optimal" directional atherectomy technique is associated with any deleterious effect on 1-year survival. In fact, had creatine kinase elevations been causally related to late death, their twofold higher incidence in the DCA arm should have been associated with a higher (not the observed lower) incidence of 1-year mortality. Nor is there any suggestion (within the limits of a 1000-patient trial and 1-year follow-up) that low-order elevations in periprocedural CPK had any deleterious effect, given the similar 1-year mortality rates for patients with (1.2%) and without (1.0%) such elevations.

### Mechanism of Restenosis Reduction

Prior studies have shown a link between larger acute procedural lumens, larger late lumens, and a reduced incidence of restenosis.\(^ {21} \) Angiographic follow-up in the BOAT trial showed a 20% relative reduction in angiographic restenosis (defined as late stenosis ≥50%), from 39.8% to 31.4% (\( P = 0.016 \)). This reduction is of the same magnitude as has been shown for the Palmaz-Schatz stent in the STRESS\(^ {14} \) trial, as would be expected given the similar posttreatment diameter stenoses for STRESS stenting (19%) and BOAT directional atherectomy (15%) relative to that of conventional balloon angioplasty (35% for STRESS and 28% in BOAT). This reduction in restenosis by DCA was obtained despite a larger late loss (0.96 versus 0.66 mm; \( P < 0.001 \)). Prior retrospective data have suggested more late loss in DCA than in stent patients matched for short-term angiographic results,\(^ {22} \) but BOAT showed an identical loss index for DCA and PTCA (slope of the late loss to acute gain relationship, 0.49 versus 0.51). The importance of a large posttreatment minimal lumen diameter (rather than which device was used to achieve it) was confirmed in the multivariate models of late lumen diameter and the probability of late restenosis, with no further independent effect of device type (DCA versus PTCA). This mirrors similar findings in CAVEAT (DCA versus PTCA), as well as STRESS and Benestent (stent versus PTCA), supporting the concept that the benefits of both stenting and DCA derive primarily from their ability to produce larger lumens in the short-term than does PTCA.

### Secondary Clinical End Points

Although the late angiographic outcome was the primary end point for BOAT, secondary late clinical end points were also prespecified.\(^ {21} \) There were 10% to 15% reductions (not statistically significant) in clinically driven TVR, TSR, and target-site failure (death, MI, or TSR). The TVR in the atherectomy arm of BOAT (17.1%) was roughly half that seen in CAVEAT\(^ {13} \) (33.7%). This low TVR rate for BOAT DCA is consistent with the 17% TVR rate in ABACAS\(^ {24} \) and the 18.9% TSR rate for DCA in NACL.\(^ {25} \) The difference in TVR rates between the BOAT treatment arms (DCA versus PTCA), however, was blunted by a parallel reduction in TVR rate for the angioplasty arm (19.7% for BOAT PTCA versus 35.0% for CAVEAT PTCA). This improvement in PTCA results is consistent with the lower residual stenosis (28% versus 36%) and the liberal use of bailout procedures (including stent [9.3%] and DCA [2.9%]) for BOAT PTCA compared with CAVEAT PTCA.

The difficulty in showing a statistically significant reduction in the secondary clinical revascularization end points (TVR and TSR) in BOAT might represent some degree of dissociation between the late angiogram and late clinical status.\(^ {26} \) The BOAT trial, however, was never powered adequately to show differences in the "noisier" secondary clinical end points, particularly once part of the potential benefit over PTCA was attenuated by the use of aggressive PTCA and bailout stenting. Such stent use was not present in earlier trials (eg, CAVEAT or CCAT), and clearly served to allow more aggressive dilation in BOAT. It effectively removed the patients with the highest residual postangioplasty stenoses and the highest probability of subsequent restenosis, explaining the observed reduction in TVR rate for PTCA (from 35% to 20%) between CAVEAT and BOAT. A similar pattern (ie, a less-pronounced difference in the clinical end point compared with the angiographic end point) has been reported in the Benestent II trial, in which stenting versus angioplasty (with provisional stenting in nearly 15% of patients) had a smaller than expected reduction in the combined clinical end point (from 15% to 19%).\(^ {27} \)

### Study Limitations

The major limitation of the BOAT study is that the DCA technique has continued to improve, so that even this study may have underestimated the potential benefits of atherectomy. Thus, although BOAT/OARS atherectomy clearly removed more plaque and left a larger acute lumen diameter than the style of atherectomy tested in CAVEAT and CCAT, ultrasound analysis in OARS shows that 60% of the original plaque mass remained. By using careful serial intravascular ultrasound guidance, the ABACAS trial\(^ {24} \) left <40% of the original plaque mass with a corresponding further reduction in
angiographic restenosis to 21% (compared with 29% in OARS and 32% in BOAT). Had intravascular ultrasound been used routinely in BOAT (rather than in 12.9% of patients, at the operator’s discretion), more plaque removal and more striking clinical and angiographic benefits may have been observed.

A second potential limitation is whether the BOAT results represent outcomes obtainable by “rank-and-file” interventionists. Although the operators who participated in BOAT were clearly experienced atherectomy operators with an interest in the procedure, they were somewhat less experienced than the OARS operators and came from multiple centers (approximating the number that participated in CAVEAT). They would thus appear to constitute an appropriate mix of experienced operators.

The third limitation is lack of statistical significance for the reduction in late clinical events. In fact, the trial was powered for the angiographic restenosis primary end point, which was positive (20% relative reduction in angiographic restenosis; \( P = .016 \)). The pattern of 13% to 17% relative reductions in secondary clinical end points such as TVR, TSR, and TVF did not, however, reach statistical significance. One explanation is that the TVR rate observed for PTCA in BOAT (19.7%) is also markedly reduced compared with historical data (35% for CAVEAT PTCA). The availability of stents during the conventional BOAT PTCA procedures may have allowed operators to dilate lesions more aggressively, with the security of knowing that stenting would be available as a bailout device. This interim enhancement in the outcomes of the PTCA arm of the study, combined with insufficient power to detect differences in the noisier clinical end points, most likely explains the marginal benefit in late secondary clinical end points observed for DCA in BOAT.

Summary
Although the directional atherectomy catheter under study was fundamentally the same as that used in CAVEAT and CCAT, BOAT used a different technique that favored larger device size, more complete tissue removal, liberal use of balloon postdilation, and emphasis on leaving a postprocedural residual stenosis <20%. This application of “optimal” atherectomy technique achieved a significantly lower posttreatment residual stenosis than BOAT conventional balloon angioplasty, CAVEAT PTCA, or CAVEAT DCA. This was achieved with significantly higher procedural success and no increase in major complications. Although the incidence of CPK-MB elevation >3X normal was higher for DCA, there was no suggestion of increased 1-year mortality compared with PTCA (0.6% versus 1.6%), suggesting that such elevations after otherwise uncomplicated procedures have no adverse consequences at 1 year. Although the larger acute lumen diameter provided by DCA in BOAT provided a significant 20% relative reduction in the angiographic restenosis primary end point, parallel 13% to 17% relative reductions in the clinical restenosis measures failed to reach statistical significance.

These findings should reassure operators who perform DCA that the procedure provides a safe and enduring alternative to conventional angioplasty in focal, de novo, noncalcified, native vessel lesions with reference diameters of 2.7 to 3.7 mm. The positioning of DCA relative to stenting is less certain because stenting may offer somewhat better outcomes, may be more broadly applicable, and may be easier to apply in situations in which either technique is possible. The differential results of CAVEAT and BOAT, however, highlight the need to refine the optimal technique for use of a new device before randomized comparison trials are begun.

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This trial was sponsored by an educational grant from Guidant DVI, Santa Clara, Calif.

Appendix
The following investigators and research coordinators (listed in descending order of enrollment) participated in BOAT.

Mt. Sinai Hospital, New York, NY: S. Sharma, D. Ratner; Scripps Memorial Hospital, La Jolla, Calif: R. Fortuna, D. Walston; St. Johns Hospital, Warten, Mbi: T.L. Schreiber, C. Trevino; Munroe Regional Medical Center, Ocala, Fl: R. Feldman, B. Merchant; Maimonides Medical Center, Brooklyn, NY: J. Shanti, N. Schuhlofs; Pensacola (Fla) Hospital: E. Rogers, E. Stock; University of Washington Hospital, Seattle: D. Stewart, B. Devine; St. Joseph’s and Pennington Hospitals, Atlanta, Ga: W.D. Knopf, K. Heselov, N. Yarborough; Graduate Hospital, Philadelphia, Pa: R. Gottlieb, J. LaVоеe; South Bend (Ind) Hospital: M. Smucker, D. Kil; Georgetown University Hospital, Washington, DC: D.J. Diver, J. Gannuscio; Maine Medical Center, Portland: M.A. Kellett, Jr; J. Conner-Kane; Lenox Hill Hospital, New York, NY: J. Moses, N. Cohen; University of Texas Health Science Center, San Antonio: S.R. Bailey, A. Briscoe; Karolinska Hospital, Stockholm, Sweden: I. Herzfeld, E. Garback; St. Thomas Hospital, Nashville, Tenn: M.H. Crenshaw, T. Wright; St. Vincent’s Hospital, Little Rock, Ark: B. Murphy, P. Sacklin; Riverside Methodist Hospital, Columbus, Ohio: S.Y. Yakubov, D. Smith; Washington University School of Medicine, St. Louis, Mo; J. Lasala, J. Frenzhold, Massachusetts General Hospital, Boston: M. Palacios, L. Harrell; Fairfair Hospital, Falls Church, Va: B. Raybuck, N. Tappe; Midwest Heart Research Foundation, Lombard, Ill: L. McKeever, E. Enger; St. Francis Hospital, Beech Grove, Ind: M.D. Cohen, D. Lee, M. Melsheimer; Cleveland Clinic Foundation, Cleveland, Ohio: P. Whileow, M. Lowrie; Emory University Hospital, Atlanta, Ga: J.S. Douglas, F. Friesch; Mount Sinai Hospital, Toronto, Ontario, Canada: A. Adelman, A. Carter; Minneapolis (Minn) Heart Institute: M.R. Moorey, G. Bauer; Mayo Clinic, Rochester, Minn: D. Holmes, J. Ramaker; Universitat zu Kiel, Kiel, Germany: R. Simon; Sanger Clinic, Charlotte, NC: C. Simonton, D.D. Applegate, C. Dellingger; St. Joseph’s Hospital, Milwaukee, Wis: D. Mathias, L. Biger; Arizona Heart Institute, Phoenix: R. Strumpf, M. Kahlstron; Medical College of Virginia, Richmond: M. Cowley, K. Kelly; Norfolk (Virginia) Sentara Hospital: C.W. Hartman, S.J. Lunow, Middle Georgia Cardiovascular Center, Macon: T. Meyer, C. Patton.


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Final Results of the Balloon vs Optimal Atherectomy Trial (BOAT)
for the BOAT Investigators

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