Operator Volume and Outcomes in 12,988 Percutaneous Coronary Interventions

PAUL D. McGRATH, MD, MSc,* DAVID E. WENNBERG, MD, MPH,*† DAVID J. MALENKA, MD, FACC,† MIRLE A. KELLETT, Jr., MD, FACC,* THOMAS J. RYAN, Jr., MD, FACC,* JOHN R. O’MEARA, MD, FACC,* WILLIAM A. BRADLEY, MD, FACC,‡ MICHAEL J. HEARNE, MD, FACC,§ BRUCE HETTLEMAN, MD, FACC,‡ JOHN F. ROBB, MD, FACC,† SAMUEL SHUBROOKS, MD, FACC,¶ MATTHEW W. WATKINS, MD, FACC,# FRANCIS L. LUCAS, PhD,* GERALD T. O’CONNOR, PhD, DSc,† for the NORTHERN NEW ENGLAND CARDIOVASCULAR DISEASE STUDY GROUP**

Portland and Bangor, Maine; Lebanon and Manchester, New Hampshire; Boston, Massachusetts; and Burlington, Vermont

Objectives. We sought to determine whether there is a relation between operator volume and outcomes for percutaneous coronary interventions (PCIs).

Background. A 1993 American College of Cardiology/American Heart Association task force stated that cardiologists should perform ≥75 procedures/year to maintain competency in PCIs; however, there were limited data available to support this statement.

Methods. Data were collected from 1990 through 1993 on 12,988 PCIs (12,118 consecutive hospital admissions) performed by 31 cardiologists at two hospitals in New Hampshire and two in Maine and one hospital in Massachusetts supporting these procedures. Operators were categorized into terciles based on annualized volume of procedures. Univariate and multivariate regression analyses were used to control for case-mix. Successful outcomes included angiographic success (all lesions attempted dilated to <50% residual stenosis) and clinical success (at least one lesion dilated to <50% residual stenosis and no adverse outcomes). In-hospital adverse outcomes included coronary artery bypass graft surgery (CABG), myocardial infarction (MI) and death.

Results. After adjustment for case-mix, higher angiographic (low, middle and high terciles: 84.7%, 86.1% and 90.3%, p-trend 0.006) and clinical success rates (85.8%, 88.0% and 90.7%, p-trend 0.025), with fewer referrals to CABG (4.54%, 3.75% and 2.49%, p-trend <0.001), were seen as operator volume increased. There was a trend toward higher MI rates for high volume operators (2.00%, 1.98% and 2.57%, p-trend 0.06); all terciles had similar in-hospital mortality rates (1.09%, 0.96% and 1.05%, p-trend 0.8).

Conclusions. There is a significant relation between operator volume and outcomes in PCIs. Efforts should be directed toward understanding why high volume operators are more successful and encounter fewer adverse outcomes.

Controversy exists regarding the relation between individual operator volume and outcomes in percutaneous coronary interventions (PCIs). Current American College of Cardiology/American Heart Association (ACC/AHA) recommendations suggest that an individual operator should perform at least 75 cases annually to remain competent (1). At the time these guidelines were published, there was little evidence in the published data addressing the relation between individual operator experience and clinical outcomes.

For some procedures, including coronary artery bypass graft surgery (CABG), abdominal aortic aneurysm resection, carotid endarterectomy and cholecystectomy, studies have indicated that the more experienced the operator or center, the better the outcome for the patient (2–5). Several studies of PCIs have identified a relation between total volume at a
success and adverse events after PCIs.

operator volume is related to angiographic success, clinical
center, clinical data base to address the question of whether
of data to clinicians (16,17). We used our prospective, multi-
process and outcome data combined with the timely feedback
vascular disease in northern New England through the analysis of
improvement in the quality of care of patients with cardiovas-
testers. The focus of the group is to foster continuous
Group (NNECVDSG) is a voluntary research consortium
outcomes has become available (9 –15).

The Northern New England Cardiovascular Disease Study
comprised of clinicians, research scientists and hospital admin-
neral improvement in the quality of care of patients with cardiovas-
cardiac catheterization laboratory were recorded on separate forms after the
Demographic and comorbidity data included age, gender, presence of diabetes, history of peripheral vascular
disease, history of chronic obstructive pulmonary disease, previous PCIs, previous CABG and previous myocardial
infarction (MI). *Previous MI* was defined as an MI that occurred
least 3 weeks before the intervention.

**Data collection.** Data for each visit to the cardiac catheter-
procedure. Demographic and comorbidity data included age,
gender, presence of diabetes, history of peripheral vascular
disease, history of chronic obstructive pulmonary disease, previous PCIs, previous CABG and previous myocardial
infarction (MI). *Previous MI* was defined as an MI that occurred
least 3 weeks before the intervention.

**Clinical data** included the indication for the procedure; the
priority of the procedure (emergency, urgent and nonurgent); whether the patient was receiving intravenous nitroglycerin or
intravenous heparin; whether the patient had an intraaortic
balloon pump (IABP) in place before the intervention; and left
ventricular ejection fraction (LVEF). **Angiographic data** in-
cluded the presence of >50% left main coronary artery
stenosis; whether the patient had >70% stenoses in the left
anterior descending coronary artery (LAD), left circumflex
artery, right coronary artery or in a bypass graft; the number of
lesions attempted; the interventional devices used; and the
location and complexity of the treated lesion or lesions. **Lesion
complexity** was defined according to ACC definitions for type
A, B and C lesions (18). The current lesion complexity
definitions, including B1 and B2 lesions, were not used at the
time these data were collected. Percent stenoses before and
after inflations were recorded by the primary operator using
visual estimates or calipers, or both, depending on the local
standard.

Successful and adverse outcomes occurring during the PCI
hospital period were assessed. Successful outcomes included
angiographic success and clinical success. **Angiographic success**
was achieved if all lesions attempted were dilated with <50%
residual stenosis; **clinical success** was defined as at least one
lesion dilated with <50% residual stenosis and no adverse
outcomes (19,20). **Adverse outcomes** assessed during the
hospital period included any CABG (emergency or nonemerg-
ecy), new MI or death. **Emergency CABG** was defined as an
operation performed to treat abrupt closure, unstable angina
or congestive heart failure requiring intravenous nitroglycerin
or IABP or tamponade resulting from the intervention. **Non-
emergency CABG** was defined as an operation performed after
an unsuccessful intervention in a clinically stable patient during
the same hospital period. A **new MI** was defined as a clinical
event, electrocardiographic changes and a creatine kinase
(actual rise to greater than or equal to twice the normal level
with positive isoenzymes.

To ensure that data were collected for all eligible patients
and that the outcomes of CABG, MI and death were correctly
assessed, the data collection was validated in the following
manner. Hospitals provided lists of discharge abstracts for
patients, which, along with catheterization laboratory logs,
were compared with the registry to identify patients for whom

**Methods**

**Patients and operators.** Data were collected on 12,118
consecutive admissions involving 12,988 PCIs performed from
January 1990 through December 1993 at two hospitals in New
Hampshire, two in Maine and one in Massachusetts supporting
these procedures. Each of these interventions was performed
by 1 of 31 primary operators. In 36 cases, the operator involved
could not be ascertained, and these procedures were excluded
from the analysis.

Annualized procedure rates for each operator were calcul-
lated in the following manner: The total number of procedures
performed by each operator was divided by the number of
months that the operator participated in the registry. This
value was then multiplied by 12 to generate an average
annualized rate. Operators were first ranked on the basis of
their annualized rates and were then categorized into low,
midle or high volume terciles. Over the 48-month study
period, only 6 of the 31 operators participated for <42 months
(2 low volume, 1 middle volume and 3 high volume operators
who each contributed from 18 to 36 months).

Of the 31 cardiologists, 2 performed additional procedures
at hospitals outside the NNECVDSG. For each of these
operators, the majority of their annual procedures was per-
formed within the NNECVDSG. The additional procedures
did not change one operator’s tercile placement. For the

Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC/AHA</td>
<td>American College of Cardiology/American Heart Association</td>
</tr>
<tr>
<td>CABG</td>
<td>Coronary artery bypass graft surgery</td>
</tr>
<tr>
<td>CK</td>
<td>Creatine kinase</td>
</tr>
<tr>
<td>IABP</td>
<td>Intraaortic balloon pump</td>
</tr>
<tr>
<td>LAD</td>
<td>Left anterior descending coronary artery</td>
</tr>
<tr>
<td>LVEF</td>
<td>Left ventricular ejection fraction</td>
</tr>
<tr>
<td>MI</td>
<td>Myocardial infarction</td>
</tr>
<tr>
<td>NNECVDSG</td>
<td>Northern New England Cardiovascular Disease Study Group</td>
</tr>
<tr>
<td>PCI</td>
<td>Percutaneous coronary intervention</td>
</tr>
<tr>
<td>PTCA</td>
<td>Percutaneous transluminal coronary angioplasty</td>
</tr>
</tbody>
</table>

center and clinical outcomes (6–8). Recently, more informa-
tion on the relation between individual operator volume and
outcomes has become available (9–15).

The Northern New England Cardiovascular Disease Study
Group (NNECVDSG) is a voluntary research consortium
employed by a variety of clinicians, research scientists and hospital admin-

**Patients and operators.** Data were collected on 12,118
consecutive admissions involving 12,988 PCIs performed from
January 1990 through December 1993 at two hospitals in New
Hampshire, two hospitals in Maine and one in Massachusetts supporting
these procedures. Each of these interventions was performed
by 1 of 31 primary operators. In 36 cases, the operator involved
could not be ascertained, and these procedures were excluded
from the analysis.

Annualized procedure rates for each operator were calcul-
lated in the following manner: The total number of procedures
performed by each operator was divided by the number of
months that the operator participated in the registry. This
value was then multiplied by 12 to generate an average
annualized rate. Operators were first ranked on the basis of
their annualized rates and were then categorized into low,
midle or high volume terciles. Over the 48-month study
period, only 6 of the 31 operators participated for <42 months
(2 low volume, 1 middle volume and 3 high volume operators
who each contributed from 18 to 36 months).

Of the 31 cardiologists, 2 performed additional procedures
at hospitals outside the NNECVDSG. For each of these
operators, the majority of their annual procedures was per-
formed within the NNECVDSG. The additional procedures
did not change one operator's tercile placement. For the
second operator, only an estimate of the number of additional
procedures was able to be obtained and may have changed this
operator's tercile placement. A separate analysis was per-
formed with this operator in a higher tercile and did not alter
the final results for any outcome.

**Data collection.** Data for each visit to the cardiac catheter-
ization laboratory were recorded on separate forms after the
procedure. Demographic and comorbidity data included age,
gender, presence of diabetes, history of peripheral vascular
disease, history of chronic obstructive pulmonary disease, previous PCIs, previous CABG and previous myocardial
infarction (MI). *Previous MI* was defined as an MI that occurred
least 3 weeks before the intervention.

**Clinical data** included the indication for the procedure; the
priority of the procedure (emergency, urgent and nonurgent); whether the patient was receiving intravenous nitroglycerin or
intravenous heparin; whether the patient had an intraaortic
balloon pump (IABP) in place before the intervention; and left
ventricular ejection fraction (LVEF). **Angiographic data** in-
cluded the presence of >50% left main coronary artery
stenosis; whether the patient had >70% stenoses in the left
anterior descending coronary artery (LAD), left circumflex
artery, right coronary artery or in a bypass graft; the number of
lesions attempted; the interventional devices used; and the
location and complexity of the treated lesion or lesions. **Lesion
complexity** was defined according to ACC definitions for type
A, B and C lesions (18). The current lesion complexity
definitions, including B1 and B2 lesions, were not used at the
time these data were collected. Percent stenoses before and
after inflations were recorded by the primary operator using
visual estimates or calipers, or both, depending on the local
standard.

Successful and adverse outcomes occurring during the PCI
hospital period were assessed. Successful outcomes included
angiographic success and clinical success. **Angiographic success**
was achieved if all lesions attempted were dilated with <50%
residual stenosis; **clinical success** was defined as at least one
lesion dilated with <50% residual stenosis and no adverse
outcomes (19,20). **Adverse outcomes** assessed during the
hospital period included any CABG (emergency or nonemerg-
ecy), new MI or death. **Emergency CABG** was defined as an
operation performed to treat abrupt closure, unstable angina
or congestive heart failure requiring intravenous nitroglycerin
or IABP or tamponade resulting from the intervention. **Non-
emergency CABG** was defined as an operation performed after
an unsuccessful intervention in a clinically stable patient during
the same hospital period. A **new MI** was defined as a clinical
event, electrocardiographic changes and a creatine kinase
(actual rise to greater than or equal to twice the normal level
with positive isoenzymes.

To ensure that data were collected for all eligible patients
and that the outcomes of CABG, MI and death were correctly
assessed, the data collection was validated in the following
manner. Hospitals provided lists of discharge abstracts for
patients, which, along with catheterization laboratory logs,
were compared with the registry to identify patients for whom

Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC/AHA</td>
<td>American College of Cardiology/American Heart Association</td>
</tr>
<tr>
<td>CABG</td>
<td>Coronary artery bypass graft surgery</td>
</tr>
<tr>
<td>CK</td>
<td>Creatine kinase</td>
</tr>
<tr>
<td>IABP</td>
<td>Intraaortic balloon pump</td>
</tr>
<tr>
<td>LAD</td>
<td>Left anterior descending coronary artery</td>
</tr>
<tr>
<td>LVEF</td>
<td>Left ventricular ejection fraction</td>
</tr>
<tr>
<td>MI</td>
<td>Myocardial infarction</td>
</tr>
<tr>
<td>NNECVDSG</td>
<td>Northern New England Cardiovascular Disease Study Group</td>
</tr>
<tr>
<td>PCI</td>
<td>Percutaneous coronary intervention</td>
</tr>
<tr>
<td>PTCA</td>
<td>Percutaneous transluminal coronary angioplasty</td>
</tr>
</tbody>
</table>
forms were missing, and missing data were then obtained. Hospital discharge abstracts served as the reference standard for validating the outcomes of CABG and death (1990 through 1993). MIs were validated (1990 through 1991) by reviewing the charts of patients whose discharge abstract contained an MI code to determine whether the MI was the indication for the procedure, was an outcome of the procedure or represented miscoding.

**Statistical analysis.** All analyses were carried out using Statistical Analysis Software, version 6.11 (21). The majority of the data collected was naturally discrete. Continuous variables such as age and LVEF were transformed into discrete categories for univariate and multivariate analyses.

Several procedural characteristics had missing data, including preprocedural intravenous heparin (missing in 4% of patients), intravenous nitroglycerin (15%), thrombolytic agents (32%) and IABP (19%). Each of these characteristics was coded as “not present” if the value was missing under the assumption that a recording would have been made had the therapy been present. Other variables with <2% missing values had these missing values also coded as “not present.” Procedures with missing values for gender (0.2%) were excluded from the multivariate analysis. LVEF was not reported in 41% of cases, and the median value for the study group was assigned to these patients. This was done after demonstrating that an indicator variable for the missing LVEFs had no significant effect when applied to the multivariate models.

Pearson chi-square tests were used to assess the univariate association between potential predictors and the outcome variables of angiographic success, clinical success, new MI, CABG and death (22). All variables demonstrating a univariate association with the event of interest, at p < 0.2 (without adjustment for multiple comparisons), were considered potential independent variables for inclusion in the multivariate analyses. Multivariate analyses were conducted using stepwise logistic regression models with entry and exit criteria set at p ≤ 0.05 (23). Age, gender and tertile were forced into all models (the logistic regression models for each of the outcome variables are provided in Appendix A). Rates for successful and adverse outcomes were then calculated using the beta-estimates from the logistic regression model, and direct standardization was used to calculate adjusted rates (24).

### Results

The majority of the operators (77%) in this data base performed percutaneous interventions at rates that exceeded ACC/AHA recommendations (1) (Table 1). Even in the low volume tertile, >70% of the operators performed procedures at annual rates above the estimated national average of <50 procedures/year (25). Therefore, although described as low volume operators in this registry, many of these operators would be considered high volume operators by national standards (25).

On average, high volume operators performed interventions in older patients, a greater proportion of women and more patients with diabetes (Table 2). High volume operators also treated more patients with significant left main coronary artery disease, three-vessel disease and a lower LVEF. In addition, operators in the middle and high volume terciles were more likely to treat patients who had undergone previous revascularization procedures or had had a previous MI.

Low and middle volume operators performed a greater proportion of procedures for postinfarction angina or for an emergency, whereas high volume operators treated more patients with unstable angina and cardiogenic shock (Table 3). Low volume operators intervened in a greater proportion of type C lesions; high volume operators performed procedures in more patients with proximal LAD lesions. Regardless of tertile, percutaneous transluminal coronary angioplasty (PTCA) was performed in the majority of cases, whereas very few procedures involved directional coronary atherectomy or stents.

Table 4 shows the unadjusted rates for in-hospital outcomes, whereas Figures 1, 2 and 3 show the case-mix adjusted rates of outcomes. After adjusting for case-mix, there was a statistically significant increase in angiographic success (p-trend 0.006) and clinical success (p-trend 0.025) as operator tertile increased.

### Table 1. Annualized Rates of Procedures by Tercile

<table>
<thead>
<tr>
<th>Tercile</th>
<th>Low</th>
<th>Middle</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of operators/tercile</td>
<td>11</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>No. of patients</td>
<td>2,275</td>
<td>3,441</td>
<td>6,402</td>
</tr>
<tr>
<td>Cases/yr</td>
<td>Mean</td>
<td>62</td>
<td>106</td>
</tr>
<tr>
<td>Median</td>
<td>68</td>
<td>102</td>
<td>221</td>
</tr>
<tr>
<td>Range</td>
<td>23–85</td>
<td>89–144</td>
<td>153–463</td>
</tr>
</tbody>
</table>

### Table 2. Clinical Characteristics by Operator Tercile

<table>
<thead>
<tr>
<th>Tercile</th>
<th>Low</th>
<th>Middle</th>
<th>High</th>
<th>p-Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age (yr)</td>
<td>60.8</td>
<td>60.9</td>
<td>62.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Women</td>
<td>31.6%</td>
<td>30.4%</td>
<td>33.5%</td>
<td>0.02</td>
</tr>
<tr>
<td>Diabetes</td>
<td>19.7%</td>
<td>19.1%</td>
<td>22.4%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>&gt;50% LMCA disease</td>
<td>1.1%</td>
<td>1.4%</td>
<td>2.4%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Three-vessel disease</td>
<td>6.8%</td>
<td>10.0%</td>
<td>13.1%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LVEF &lt;40%</td>
<td>5.2%</td>
<td>6.5%</td>
<td>8.5%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Previous PTCA</td>
<td>24.3%</td>
<td>26.1%</td>
<td>27.5%</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Previous CABG</td>
<td>8.0%</td>
<td>9.1%</td>
<td>12.6%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Previous MI</td>
<td>19.9%</td>
<td>25.5%</td>
<td>23.1%</td>
<td>0.01</td>
</tr>
<tr>
<td>Preprocedural Tx</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV heparin</td>
<td>54.8%</td>
<td>55.8%</td>
<td>46.6%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>IV nitroglycerin</td>
<td>16.9%</td>
<td>23.4%</td>
<td>22.7%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Thrombolytic agents</td>
<td>8.1%</td>
<td>8.0%</td>
<td>6.0%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Preprocedural IABP</td>
<td>0.4%</td>
<td>0.3%</td>
<td>0.4%</td>
<td>0.7</td>
</tr>
</tbody>
</table>

CABG = coronary artery bypass graft surgery; IABP = intraaortic balloon pump; IV = intravenous; LMCA = left main coronary artery; LVEF = left ventricular ejection fraction; MI = myocardial infarction; PTCA = percutaneous transluminal coronary angioplasty; Tx = therapy.
volume increased (Fig. 1). In the analyses of adverse outcomes (Fig. 2), there was a small increase in the adjusted rate of postprocedural MI as operator volume increased, although this difference was not statistically significant after adjustment for case-mix (p-trend 0.06). However, there was a large, statistically significant difference in the postprocedural rates of CABG during the same admission (p-trend 0.001). Patients treated by high volume operators had a 45% lower risk of undergoing a post-PCI CABG. This decrease in CABG rates was found for both emergency (p-trend 0.001) and nonemergency procedures (p-trend <0.001) (Fig. 3). Patients treated by operators in each tercile had a nearly identical case-mix adjusted risk of in-hospital mortality (p-trend 0.8).

**Table 3. Indication, Priority, Lesion Characteristics and Device by Operator Tercile**

<table>
<thead>
<tr>
<th>Tercile</th>
<th>p-Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Middle</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indication for 1st procedure</th>
<th>p-Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asymptomatic CAD</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stable angina</td>
<td>0.8</td>
</tr>
<tr>
<td>Unstable angina</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Postinfarction angina</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Postinfarction anatomy</td>
<td>0.06</td>
</tr>
<tr>
<td>Primary therapy for MI</td>
<td>0.09</td>
</tr>
<tr>
<td>Cardiogenic shock</td>
<td>0.02</td>
</tr>
<tr>
<td>Other</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Priority of 1st procedure**

<table>
<thead>
<tr>
<th>p-Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency</td>
</tr>
<tr>
<td>Urgent</td>
</tr>
<tr>
<td>Nonurgent</td>
</tr>
</tbody>
</table>

| No. of lesions attempted   | <0.001  |
| Proximal LAD attempted    | <0.001  |

**Lesion type**

<table>
<thead>
<tr>
<th>p-Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
</tbody>
</table>

**Angioplasty only**

<table>
<thead>
<tr>
<th>p-Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03</td>
</tr>
</tbody>
</table>

**DCA involved**

<table>
<thead>
<tr>
<th>p-Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
</tr>
</tbody>
</table>

**Stent placement involved**

<table>
<thead>
<tr>
<th>p-Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
</tr>
</tbody>
</table>

*The worst lesion type (according to the American College of Cardiology) treated during the first procedure. CAD = coronary artery disease; DCA = directional coronary atherectomy; LAD = left anterior descending coronary artery; MI = myocardial infarction.

### Discussion

The present study demonstrates two important relations between operator volume and outcomes for PCIs: 1) Higher operator volume is associated with a greater degree of angiographic and clinical success; and 2) lower operator volume is associated with an increased likelihood of postprocedural CABG. Notably, a significant difference in in-hospital mortality across terciles was not present.

**Previous studies.** Other studies have attempted to address the relation between individual operator volume and outcomes. Because of concerns about the power of single-center studies to detect such a relation, and the possible interaction between operator volume and hospital volume, single-center versus multicenter studies are considered separately.

Hamad et al. (11) studied the results of 781 PTCA procedures performed at one institution by either high (>100 PTCA procedures/year) or low volume operators (<100 PTCA procedures/year) and concluded that low volume operators had poorer outcomes when more complex lesions were involved. Another study (12) involving 2,350 PTCA procedures performed by high (>50 PTCA procedures/year) and low volume

**Table 4. Unadjusted Rates for In-Hospital Outcomes**

<table>
<thead>
<tr>
<th>Outcome/Complication</th>
<th>Tercile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Angiographic success</td>
<td>84.3%</td>
</tr>
<tr>
<td>Clinical success</td>
<td>85.1%</td>
</tr>
<tr>
<td>New MI</td>
<td>1.9%</td>
</tr>
<tr>
<td>Any CABG</td>
<td>4.0%</td>
</tr>
<tr>
<td>Emergency</td>
<td>2.3%</td>
</tr>
<tr>
<td>Nonemergency</td>
<td>1.9%</td>
</tr>
<tr>
<td>In-hospital mortality</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

**Figure 1.** Relation between volume tercile and case-mix adjusted rates of angiographic (all lesions attempted successfully dilated to <50% residual stenosis), and clinical success (at least one lesion dilated to <50% residual stenosis and no adverse clinical events). For model covariates, see Appendix A. Patterned, open and solid bars = low, medium and high volume tertiles, respectively.

**Figure 2.** Relation between volume tercile and in-hospital case-mix adjusted rates of MI, CABG and death. For model covariates, see Appendix A. Symbols as in Figure 1.
operators (<50 PTCA procedures/year) at a single institution found differences in the rates of emergency CABG (2.1% for high volume, 3.9% for low volume operators), differences that parallel our results. A more recent study (14) from a single center found no significant difference between operator volume and outcomes, but involved only 1,389 procedures from 1993 through 1995.

Jollis et al. (7) studied 1992 Medicare discharge abstracts for 97,478 patients who had PCIs performed by 6,115 physicians. Although there was no significant difference in inhospital or 30-day mortality, a statistically significant difference for subsequent in-hospital CABG was found. The rates for in-hospital CABG were 3.8%, 3.4% and 2.6% for patients treated by physicians with an average volume of <25, 25 to 50 and >50 PCIs/year, respectively (p < 0.001). A recently published study (13) of the 1991 to 1994 New York state experience with 62,670 patients treated by >100 physicians discovered significant differences in patients undergoing PCIS performed by cardiologists with annual volumes <75 PCIS/year. These patients had a risk-adjusted mortality rate of 1.03%, compared with 0.90% for all patients, and a same-stay risk-adjusted CABG rate of 3.95%, compared with 3.43% for all patients (13). Ellis et al. (9) analyzed data bases from five high volume centers involving 12,985 patients undergoing PCIS during 1993 to 1994 and also found a significant, inverse relation between operator volume and the combined end point of death, Q wave MI or the need for emergency CABG.

With respect to angiographic and clinical success, Ellis et al. (20) used a comparable definition for success, where “procedural success” was defined as a final stenosis <50% and no death, MI or CABG. Their overall procedural success rate was 86.8%. Hannan et al. (19) used a similar definition and defined clinical success as a final stenosis <50% and no death, MI or CABG. Their overall clinical success rate was 87.0%.

There have been several concerns raised over attempts to assess the relation between operator volume and patient outcomes. These concerns include inadequate numbers of patients studied given the low incidence of major adverse events (20), the subjective reporting of certain outcomes (20) and the failure to adequately adjust for case-mix (26). The large, multicenter, clinical data base used for the present study allowed sufficient power in the current analysis to detect differences across terciles of operator volume for all outcomes except death. Although the subjective reporting of angiographic and clinical success remains a concern in the present study, the effect of individual operator bias would have less of an effect on the current analysis, which focused on terciles rather than individual operators. Furthermore, differences were demonstrated in CABG rates, an objective end point, while the extensive list of clinical variables included in this data base allowed for case-mix adjustment.

Study limitations. There are several limitations to our study. Although the CABG and mortality data were verified, the MI data were validated only from 1990 through 1991. Separate analyses were performed for the 1990 to 1991 data as well as for the entire data set to address this issue. The relation between volume and outcomes was the same for both analyses, suggesting that there is no systematic underreporting of MIs by high volume operators. There may be concern that high volume operators are “accepting” procedure-related MIs instead of referring their patients for CABG. However, even if one assumed that all patients with MIs treated by high volume operators could have been referred for CABG, this would not account for the large differences in rates of CABG across terciles. Finally, although CK levels were not routinely measured after all procedures, there is no a priori reason why there would be differential reporting of MIs across terciles.

The number of centers involved limits our ability to separate the operator effect from the center effect on a given outcome. Several studies have addressed the relation between the volume of procedures performed at a given center and patient outcomes. Catheterization laboratories performing a higher number of PTCA procedures have been shown (6–8) to have lower subsequent CABG and mortality rates. In addition, Hannan et al. (13) showed that there is an interaction between operator volume and hospital volume, such that low volume operators practicing in higher volume centers with >600 PCIS/year have better outcomes than low volume operators practicing in low volume centers with <600 PCIS/year (13). The majority of low volume operators (73%) in our study performed procedures at centers with annual rates of >700 PCIS/year, presumably serving to limit any significant center effect; the remaining operators performed procedures at centers with >300 PCIS/year.

The outcomes assessed in the present study are in-hospital outcomes. The current data base does not allow us to address outcomes over a longer time frame that may differ from those encountered during a patient’s hospital period. Finally, few of these procedures involved the placement of stents. The recent increase in the use of stents may alter the rates of successful and adverse outcomes across terciles.

Study implications. The results of the current study raise the question of how to use this information to improve patient outcomes (27). One approach would be to revise the 1993 ACC/AHA guidelines and suggest that competency in inter-
ventricular cardiology requires performing even higher numbers of procedures. The natural extension of this would be to limit PCIs to a small group of high volume operators and institutions within a region, as has been suggested for CAGB (28). Given the relations that we observed between volume and outcomes, exactly what number of annual procedures to recommend on the basis of our study is unclear.

An alternative approach would be to determine why higher volume operators have better outcomes than lower volume operators. The differences in outcomes may relate to technical skills, decision making or some other aspect of the process of patient care. O’Connor et al. (29) demonstrated that when cardiothoracic surgeons collaborate to better understand the details and dynamics involved with CAGB, patient outcomes improve significantly. We would suggest that similar results may be possible with PCIs. Future efforts should be directed toward understanding what high volume operators do differently. This information can then be disseminated to all levels of operators, with the aim of improving overall outcomes for patients undergoing PCIs.

Appendix A

Logistic Regression Models for Each of the Outcome Variables

1. Angiographic success: Age, gender, tercile, three-vessel disease, LVEF <40%, previous PTCA, intravenous heparin, emergency case, directional coronary athereectomy, number of lesions attempted and ACC lesion type.

2. Clinical success: Age, gender, tercile, three-vessel disease, LVEF <40%, previous PTCA, intravenous nitroglycerin, intravenous heparin, IABP, emergency case, directional coronary athereectomy, number of lesions attempted and ACC lesion type.

3. Myocardial infarction: Age, gender, tercile, three-vessel disease, intravenous heparin, previous PTCA, emergency case and ACC lesion type.

4. Any CABG: Age, gender, tercile, diabetes, proximal LAD attempted, mid-LAD attempted, graft attempted, intravenous nitroglycerin, previous PTCA, emergency case, number of lesions attempted and ACC lesion type.

5. Emergency CABG: Age, gender, tercile, diabetes, proximal LAD attempted, mid-LAD attempted, graft attempted, previous PTCA, emergency case, number of lesions attempted and ACC lesion type.


7. In-hospital mortality: Age, gender, tercile, diabetes, three-vessel disease, LVEF <40%, proximal LAD attempted, intravenous nitroglycerin, IABP, emergency case and previous PTCA.

Appendix B

Members of the Northern New England Cardiovascular Disease Study Group

Eastern Maine Medical Center, Bangor, Maine: Deborah Carey-Johnson, RN, MS, Robert Clough MD, Cynthia M. Downes, RN, MSN, Felix Hernandez, Jr., MD, Joseph J. Hessel, MD, Robert M. Hoffman, MD, Edward R. Johnson, MD, Helen McKinnon, RN, Cathy Mingo, RN, MS, Craig Pedersen, PA, Wendy Perkins, LPN, Matthew L. Rowe, MD, Katrina Sargent, Ted Silver, MD, Peter Ver Lee, MD, Craig Warren, CCP.

Fletcher Allen Health Care, Burlington, Vermont: Shelley Barber, RN, Richard G. Brandenburg, PhD, Laurence H. Coffin, MD, Steve Colmanaro, PA, Walter D. Gundel, MD, Richard S. Jackson, MD, David Johnson, MD, Ann Lamarree, RN, Bruce J. Leavitt, MD, William C. Paganeli, PhD, Diane Pappalardo, MHSA, Daniel S. Raabe, MD, Christopher Terrien, MD, Matthew Watkins, MD.

Dartmouth-Hitchcock Medical Center, Lebanon, New Hampshire: Virginia Beggs, MS, ARNP, John D. Birnkmyer, MD, William Burke, RCVT, Edward Caithrowood, MD, Lawrence J. Dacey, MD, Gordon Defoe, CCP, Thomas Dodds, MD, Mary Fillinger, M.D., Bruce Friedman, MD, Bruce Hettlemann, MD, Terry Kneeland, MPH, Elizabeth Maiken, ARNP, David Malenka, MD, Charles A.S. Marrin, MB, BS, Nathaniel Niles, MD, William C. Nugent, MD, Nancy J. O’Connor, MS, Gerald T. O’Connor, PhD, Dse, Elaine M. Olmstead, BA, Stephen K. Plume, MD, Hebe B. Quinton, AB, John Robb, MD, William Schults, William F. Sullivan, Jon Wahrenberger, MD, Beth Wolf.

Catholic Medical Center, Manchester, New Hampshire: Yvonne Baribeau, MD, Ann Becker, RN, Craig C. Berry, MD, Kevin Berry, MD, William A. Bradley, MD, David C. Charlesworth, MD, S. Cuddy, RN, Robert C. Dewey, MD, Frank Fedele, MD, Louis I. Fink, MD, Erik J. Funk, MD, Alan E. Garska, MD, Dan Halstal, CCP, MD, James H. Heerlein, MD, J. Beaty Hunter, MD, Alan D. Kaplan, MD, Peggy Lambert, RN, Patrick M. Lawrence, MD, Jeffery Lockhart, MD, Christopher T. Maloney, MD, Kathy McNeil, RN, Edward Palank, MD, M. Judith Porelle, RN, Donna Pulsifer, RN, Joanne Robichaud, RN, James Schmitz, MD, Shirley Shea, RN, JD, MD, Benjamin M. Westbrook, MD, Thomas P. Wharton, MD, Kirke W. Wheeler, MD, Dee White, RN.

Maine Medical Assessment Foundation, Augusta, Maine: Robert B. Keller, MD, David C. Soule, BA, David Wennberg, MD, MPH.

Maine Medical Center, Portland, Maine: Mary Abbott, MS, RN, Lawrence Adrian, PA, Warren D. Alpern, MD, Eric Anderson, Richard A. Anderson, MD, Linda Banister, RN, Claire Berg, RN, Seth Blank, MD, Michael Brennan, PA, Linda Brewster, MSN, David Burkey, MD, Cantwell Clark, MD, Jane Cleaves, RN, Deborah Courtney, RN, MS, D. Joshua Cutler, MD, Desmond Donnegan, MD, Pat Fallo, RN, Daniel Hanley, MD, Jane Kane, RN, Saul Katz, MD, Mirle A. Kellett, Jr., MD, Robert Kramer, MD, Costas T. Lambew, MD, F. Stephen Larncd, MD, Chris A. Lutes, MD, Paul D. McGrath, MS, Jeremy R. Morton, MD, Edward R. Nowicki, MD, John R. O’Meara, MD, Patricia Peasley, RN, Cathy Prouty, RN, Reed D. Quinn, MD, Dennis Redfield, RN, Karen Reynolds, MPH, Thomas Ryan, Jr., MD, Jean Saunders, MSN, MPH, Alice Schultz, RN, PhD, Susan Seckins, RN, Karen Tolan, RN, Joan F. Try zeal, MD, Marie Turcotte, RN, Kathy Viger, RN, Cynthia Westlund, RN, Richard L White, RN, Wanda Whittet, RN, Carol Zografos, CCP.

Beth Israel-Deaconess Hospital, Boston, Massachusetts: Philip J. Fitzpatrick, MD, Wendy L. Kowalker, David Leeman, MD, Stanley Lewis, MD, Richard Nesto, MD, Samuel Shubrooks, MD, Paul G. Vivino, MD, Albert Washko.

References


