Relation Between Operator and Hospital Volume and Outcomes Following Percutaneous Coronary Interventions in the Era of the Coronary Stent

Paul D. McGrath, MD, MSc
David E. Wennberg, MD, MPH
John D. Dickens, Jr, MD
Andrea E. Siewers, MPH
F. Lee Lucas, PhD
David J. Malenka, MD
Mirle A. Kellett, Jr, MD
Thomas J. Ryan, Jr, MD

Previous studies have assessed the association of physician and hospital experience with patient morbidity and mortality following a variety of procedures. Controversy exists in the field of cardiology regarding experience with percutaneous coronary interventions (PCIs) such as balloon angioplasty and coronary stent procedures. The current debate focuses on the annual volume of procedures that should be performed by a physician or institution to optimize patient outcomes.

Many of the studies of procedure volume and patient outcomes for PCIs have found a strong relationship between the procedural volume of the operating physician or center and patient outcomes. Patients treated by high-volume physicians and at high-volume centers have been shown to experience a higher rate of successful procedures, lower mortality rates, and a lower risk of subsequent coronary artery bypass graft (CABG) surgery during the same admission. Guidelines from the American College of Cardiology (ACC) have used these data to establish recommendations for both physicians and hospitals with respect to a minimum annual volume of PCIs performed. Current guidelines recommend that physicians and hospital PCI volume.

Context Studies have found an association between physician and institution procedure volume for percutaneous coronary interventions (PCIs) and patient outcomes, but whether implementation of coronary stents has allowed low-volume physicians and centers to achieve outcomes similar to their high-volume counterparts is unknown.

Objective To assess the relationship between physician and hospital PCI volumes and patient outcomes following PCIs, given the availability of coronary stents.

Design, Setting, and Participants Analysis of data from Medicare National Claims History files for 167,208 patients aged 65 to 99 years who had PCIs performed by 6,534 physicians at 1,003 hospitals during 1997. Of these procedures, 57.7% involved coronary stents.

Main Outcome Measures Rates of coronary artery bypass graft (CABG) surgery and 30-day mortality occurring during the index episode of care, stratified by physician and hospital PCI volume.

Results Overall unadjusted rates of CABG during the index hospitalization and 30-day mortality were 1.87% and 3.30%, respectively. After adjustment for case mix, patients treated by low-volume (<30 Medicare procedures) physicians had an increased risk of CABG vs patients treated by high-volume (>60 Medicare procedures) physicians (2.25% vs 1.55%; P < .001), but there was no difference in 30-day mortality rates (2.35% vs 3.39%; P = .27). Patients treated at low-volume (<80 Medicare procedures) centers had an increased risk of 30-day mortality vs patients treated at high-volume (>160 Medicare procedures) centers (4.29% vs 3.15%; P < .001), but there was no difference in the risk of CABG (1.83% vs 1.83%; P = .96). In patients who received coronary stents, the CABG rate was 1.20% vs 2.78% for patients not receiving stents, and the 30-day mortality rate was 2.83% vs 3.94%. Among patients who received stents, those treated at low-volume centers had an increased risk of 30-day mortality vs those treated at high-volume centers, whereas those treated by low-volume physicians had an increased risk of CABG vs those treated by high-volume physicians.

Conclusion In the era of coronary stents, Medicare patients treated by high-volume physicians and at high-volume centers experience better outcomes following PCIs.

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See also pp 3131 and 3169 and Patient Page.
Cardiovascular physicians perform at least 75 procedures and hospitals perform at least 400 procedures annually.17 Recent advances in technology have reduced complications following PCI, including the risk of undergoing subsequent CABG surgery.16 These advances include the advent of coronary stents.18 To date, there is a relative paucity of literature describing the relationship between volume and outcome for PCIs involving coronary stents. Therefore, we assessed the volume and outcome relationship for Medicare enrollees with data collected since the widespread implementation of the coronary stent.

METHODS

Data Sources and Study Population

Medicare National Claims History files used for the analysis consisted of both Part A (hospital) and Part B (physician) claims. Part A files for each hospitalization billed to Medicare contain personal identifier numbers, demographic data, hospital identification codes, dates of admission and discharge, up to 10 discharge diagnoses and procedures as identified by International Classification of Diseases (ICD-9) codes,19 urgency of admission, and vital status at discharge. Part B files contain personal identifier numbers, demographic data, physician identification numbers, and procedure data based on Current Procedural Terminology (CPT) codes.20

The study population included all Medicare enrollees aged 65 to 99 years undergoing PCIs in 1997. For any given patient, the first hospitalization for a PCI in 1997 was used to avoid counting patients more than once. Only enrollees with both Part A and Part B claims for the index PCI were included in the analysis.

Outcome Variables

The outcomes of interest included CABG following a PCI, 30-day mortality, and the combined end point of CABG or 30-day mortality. For each Medicare enrollee’s index PCI in 1997, the personal identifier number was used to link claims and create a longitudinal record representing the episode of care. All admissions associated with the PCI were identified using Part A data, including transfers between acute care facilities for subsequent care. Using this method, adverse outcomes within the same episode of care were identified.

Calculation of Physician Volume and Hospital Volume

Physician PCI volume was calculated by counting all 1997 Medicare claims for angioplasty, stent, or atherectomy (CPT codes 92980, 92981, 92982, 92984, 92995, 92996). Each PCI performed on a Medicare enrollee was credited to 1 physician. When multiple physicians submitted claims for the PCI, the physician with the greatest workload, as defined by relative value units (based on the current Medicare physician fee schedule), was credited with the procedure. Hospital PCI volume was calculated by counting all claims for coronary angioplasty, stent, or atherectomy (ICD-9 codes 36.01, 36.02, 36.04, 36.05, 36.06, 36.09) performed at that facility in 1997. Physicians with only 1 procedure per year and hospitals with fewer than 5 procedures per year were excluded from the analysis to limit the effect of potential coding errors.

Current ACC guidelines recommend that physicians perform at least 75 PCIs annually and that at least 400 PCIs be performed at hospitals annually.17 Percutaneous coronary interventions performed on the Medicare population represent 35% to 45% of total PCI volume.21,22 We estimated that 30 such PCIs would approximate a total procedure volume of 75 PCIs for physicians (Medicare and non-Medicare patients) and 160 such PCIs would approximate a total procedure volume of 400 PCIs for hospitals. For hospital volume, we also assessed a Medicare volume of 80 PCIs per year to approximate the total annual institutional volume of 200 PCIs recommended in earlier ACC guidelines.23 Using these estimates, we stratified physicians and hospitals into low-, intermediate-, and high-volume categories. Using Medicare volume as a proxy for total volume, low-volume physicians (<30 PCIs per year) and low- and intermediate-volume hospitals (<160 PCIs per year) would be unlikely to meet the minimum volume for PCIs recommended in current guidelines.

Patient Characteristics

Patient characteristics collected included age, sex, race, urgency of admission (elective, urgent, emergency), acute myocardial infarction (AMI), comorbidity, and the number of vessels revascularized (single-vessel or multivessel PCI). Admissions for AMI were identified as a primary diagnosis of AMI, or a primary diagnosis of a complication of AMI with a secondary diagnosis of AMI, and a length of stay longer than 2 days for all patients discharged alive. Comorbidity was determined using the Dartmouth-Manitoba modification of the Charlson comorbidity index (scored as 0, 1, or ≥2).24

Analysis

The primary outcomes were subsequent CABG occurring during the same episode of hospital care, or 30-day mortality. Patients were stratified based on their associated physicians’ and hospitals’ annual volume of Medicare PCIs. Patient characteristics and outcomes were compared across volume strata. Logistic regression models were used to adjust for patient characteristics while assessing the relationship between PCI volume and adverse outcomes.25 All analyses were carried out using SAS26 and StATA27 statistical software. χ² Tests were used to assess differences across categories and analysis of variance tests were used to assess differences among means.28 No significant interactions between physician and hospital volume were found for any of the outcomes assessed. We accounted for clustering of outcomes within providers using mixed effects models.27 Following multivariate analysis with logistic regression, direct standardization techniques were used to generate adjusted rates of CABG, 30-day mortality, and the combined end point of CABG or 30-day mortality.29
RESULTS
Our analysis involved 167,208 Medicare patients who underwent at least 1 PCI during 1997. A total of 6,534 physicians performed these procedures at 1003 hospitals. The mean age of the patient population was 73.6 years, 44.1% were women, and 57.7% of PCIs involved coronary stents.

Patient characteristics across physician and hospital volume categories are presented in Table 1. Given the large data set used for the analysis, statistically significant differences were found across volume categories for most variables in the analysis. Lower-volume physicians and hospitals were more likely to perform PCIs on patients admitted with a diagnosis of myocardial infarction. Higher-volume physicians and hospitals were more likely to perform PCIs for patients with a greater degree of comorbidity as measured by the Charlson score.24 These procedures performed by high-volume physicians were more likely to involve a multivessel procedure and more frequently included the use of a coronary stent. For the study population overall, unadjusted rates of CABG, 30-day mortality, and the combined end point of CABG during the same hospitalization or 30-day mortality were 1.87%, 3.30%, and 4.96%, respectively.

With respect to physician volume, both unadjusted and adjusted CABG and 30-day mortality rates are presented in Table 2. The unadjusted rates demonstrate a significant relationship between physician volume and CABG as well as 30-day mortality. After adjusting for case mix, a significant difference remained across volume strata for the adverse outcome of same hospitalization CABG surgery. The rate of CABG for patients treated by low-volume physicians was 2.25% compared with 1.55% for patients treated by high-volume physicians, a 45% increase in risk of CABG (P<.001). After adjusting for case mix, there was no significant difference in 30-day mortality rates across physician volume categories. Mortality rates ranged from 3.25% for patients treated by low-volume physicians to 3.39% for patients treated by high-volume physicians (P=.27). Rates for the combined end point of CABG surgery or 30-day mortality were 5.26% for patients treated by low-volume physicians compared with 4.75% for patients treated by high-volume physicians (P=.002).

Across categories of hospital volume, a significant relationship between physician volume and both CABG and 30-day mortality was demonstrated for the unadjusted rates (Table 3). After adjustment for case mix, patients treated at low-volume centers had no difference in risk of CABG (1.83% vs 1.83%, P=.96), but had a 36% increased risk of mortality when compared with patients treated at high-volume hospitals (4.29% vs 3.15%, P<.001). Patients treated at low-volume centers had a 22% increased risk of the combined end point of CABG or mortality compared with patients treated at high-volume centers (5.87% vs 4.78%, P<.001).

To further describe the trend for outcomes across volume categories adjusted rates are presented in the Figure.

Table 1. Patient Characteristics by Annual Physician and Hospital Medicare PCI Volume*

<table>
<thead>
<tr>
<th>Physician Medicare PCI Volume per Year</th>
<th>Hospitals Medicare PCI Volume per Year</th>
<th>P Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Providers, No. (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;30</td>
<td>3562 (64.5)</td>
<td></td>
</tr>
<tr>
<td>30-60</td>
<td>1767 (27.0)</td>
<td></td>
</tr>
<tr>
<td>&gt;60</td>
<td>1205 (18.5)</td>
<td></td>
</tr>
<tr>
<td>Patients, No. (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;30</td>
<td>33,539 (20.0)</td>
<td></td>
</tr>
<tr>
<td>30-60</td>
<td>51,519 (30.8)</td>
<td></td>
</tr>
<tr>
<td>&gt;60</td>
<td>82,150 (49.2)</td>
<td></td>
</tr>
</tbody>
</table>

†Comparisons among physician or hospital strata.

Table 2. Rates of CABG or 30-Day Mortality Following PCI According to Annual Physician PCI Volume Among Medicare Beneficiaries*

<table>
<thead>
<tr>
<th>CABG following PCI</th>
<th>Unadjusted Rates, Physician Medicare PCI Volume</th>
<th>Adjusted Rates, Physician Medicare PCI Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30</td>
<td>2.39 &lt;.001</td>
<td>2.25 &lt;.001</td>
</tr>
<tr>
<td>30-60</td>
<td>3.52 .004</td>
<td>3.25 .27</td>
</tr>
<tr>
<td>&gt;60</td>
<td>5.66 &lt;.001</td>
<td>5.26 .002</td>
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</tbody>
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†P values compared to reference group (>60 category).

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with patients grouped into deciles based on physician volume and hospital volume. Adjusted rates of the combined end point of in-hospital mortality and CABG were 5.21% for the lowest physician volume category and 4.80% for the highest physician volume category. Adjusted rates of the combined end point of in-hospital mortality and CABG were 5.95% for the lowest hospital volume category and 4.10% for the highest hospital volume category.

The most favorable outcomes were observed at the highest-volume centers with the highest-volume physicians (TABLE 4). When physician volume exceeded 60 Medicare PCIs per year and hospital volume exceeded 160 Medicare PCIs per year, the composite end point of CABG or mortality occurred in 4.59% of cases compared with 6.13% for low-volume physicians operating at low-volume hospitals ($P<.001$). The combined end point of 30-day mortality and CABG was 6.13% for low-volume physicians at low-volume centers compared with 5.06% for low-volume physicians at high-volume centers.

An additional analysis was performed to assess the impact of including hospitals performing fewer than 5 PCIs in the Medicare population and physicians billing Medicare for only 1 PCI. These cases were excluded from the primary analysis to limit the potential for coding error. When these cases were included in the subgroup analysis, the results were similar to those in the main analysis (data not shown).

Two subanalyses were performed, evaluating outcomes for patients receiving or not receiving coronary stents. The unadjusted CABG rate for patients receiving stents was 1.20%, compared with 2.78% for patients not receiving coronary stents. The overall unadjusted 30-day mortality rate for patients receiving stents was 2.83%, compared with 3.94% for patients not receiving coronary stents. Following multivariate adjustment, the main results observed in the primary analysis remained for both stented and nonstented patients, ie, patients who received stents had an increased risk of mortality at low-volume hospitals (3.48% vs 2.75%; $P=.007$) and an increased risk of CABG with low-volume physicians (1.38% vs 1.09%; $P=.004$). For 30-day mortality, both stented and nonstented patients treated by low-volume physicians had an overall mortality rate comparable to patients treated by high-volume physicians (3.25% vs 3.39%; $P=.27$).

**Table 3. Rates of CABG or 30-Day Mortality Following PCI According to Annual Hospital PCI Volume Among Medicare Beneficiaries**

<table>
<thead>
<tr>
<th>Unadjusted Rates, Hospital Medicare PCI Volume</th>
<th>Adjusted Rates, Hospital Medicare PCI Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;80$ $P$ Value† $80-160$ $P$ Value† $&gt;160$ $P$ Value† $80$ $P$ Value† $80-160$ $P$ Value† $&gt;160$ $P$ Value†</td>
<td></td>
</tr>
<tr>
<td>CABG following PCI 2.26 $&lt;.001$ 2.36 $&lt;.001$ 1.76 $&lt;.001$ 1.83 $&lt;.001$ 2.09 $&lt;.001$ 1.83 $&lt;.001$</td>
<td></td>
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<tr>
<td>30-day mortality 4.88 $&lt;.001$ 3.86 $&lt;.001$ 3.11 $&lt;.001$ 4.29 $&lt;.001$ 3.75 $&lt;.001$ 3.15 $&lt;.001$</td>
<td></td>
</tr>
<tr>
<td>CABG or 30-day mortality following PCI 6.88 $&lt;.001$ 5.94 $&lt;.001$ 4.68 $&lt;.001$ 5.87 $&lt;.001$ 5.59 $&lt;.001$ 4.78 $&lt;.001$</td>
<td></td>
</tr>
</tbody>
</table>

*All rates are percentages. CABG indicates coronary artery bypass graft; PCI, percutaneous coronary intervention. Adjusted for age, sex, race, acute myocardial infarction as primary diagnosis, comorbidity score, urgency of admission, multivessel PCI, and physician volume.†P values compared to reference group ($>80$ category).

**Figure.** Adjusted Rates of 30-Day Mortality and CABG Following PCI Among Medicare Beneficiaries During 1997, According to Physician and Hospital Medicare PCI Volumes, in Deciles

CABG indicates coronary artery bypass graft; PCI, percutaneous coronary intervention. Adjusted for age, sex, race, acute myocardial infarction as primary diagnosis, comorbidity score, urgency of admission, and multivessel PCI. Data points reflect the adjusted means of the deciles.
However, patients who received stents and were treated by low-volume physicians had a slightly lower mortality risk compared with patients receiving coronary stents who were treated by high-volume physicians (2.60% vs 3.00%; P = .01).

**COMMENT**

Our study results show that, in the era of the coronary stent, a significant relationship remains with respect to physician and hospital PCI volumes and patient outcomes following PCIs. Medicare patients treated by high-volume physicians are less likely to require CABG during the same episode of care. Patients treated at high-volume centers encountered a lower risk of 30-day mortality when compared with patients treated at low-volume centers.

Our findings regarding the relationship between volume and outcome are similar to the results of previous studies performed prior to the widespread use of coronary stents. Jollis and colleagues performed a similar analysis involving 97478 Medicare claims from 1992 involving 6115 physicians. Overall same-admission CABG rates were higher in 1992 than in the current study (3.3% vs 1.87%). Thirty-day mortality rates were similar: 2.9% in 1992 vs 3.30% in the current study. During 1992 there was not a significant difference in rates of in-hospital or 30-day mortality, although a statistically significant difference was found for subsequent in-hospital CABG. The 1992 rates for in-hospital CABG in the Medicare population were 3.8%, 3.4%, and 2.6% for patients treated by physicians with average volumes of fewer than 25, 25 to 50, and 50 or more PCIs per year, respectively (P < .001).

The 1991-1994 New York state study, with 62670 patients and 130 to 163 physicians during the study period, reported significant differences in patients undergoing PCIs performed by cardiologists with annual volumes of fewer than 75 total PCIs per year. These patients had risk-adjusted mortality rates of 1.03% compared with 0.90% for all patients and same-stay risk-adjusted CABG rates of 3.93% compared with 3.43% for all patients. The Northern New England study from 1990-1993, involving 12988 PCIs performed by 31 cardiologists, found that patients treated by more experienced physicians encountered greater success confirmed by angiography and lower rates of subsequent CABG.

More recent studies have attempted to address the association of the use of coronary stents with improving outcomes. Maynard et al used data from California hospitals obtained from 1993 and 1996 to assess outcomes before and after the introduction of coronary stents. For patients without a principal diagnosis of AMI, patients at low-volume centers experienced rates of same-admission CABG of 3.5% compared to 2.2% for high-volume centers. In a 1994 through 1996 follow-up of the Northern New England study, Malenka et al did not find a significant difference in CABG rates and mortality across volume categories of physicians. However, the fact that the lowest-volume physicians performed an average of 68 PCIs per year at high-volume centers may have in part accounted for the different findings with respect to physician volume when compared with the present Medicare analysis.

Several concerns have been raised about attempts to assess the relationship between physician PCI volume and patient outcomes after PCI. These include inadequate numbers of patients studied given the low incidence of major adverse events, the subjective reporting of certain outcomes, and failure to adjust adequately for case mix.

The large, national database used for our study allowed sufficient power to determine whether significant differences in adverse outcomes were present across categories of physician PCI volume. Our study adjusted for case mix, but is limited to the patient and hospitalization characteristics available through Medicare claims. We also have described a higher use of coronary stents by more experienced physicians. We are unable to determine the reason for the higher rate of stent use by high-volume physicians. High-volume physicians may have a propensity to use these devices initially during PCIs or they may have the ability to use these devices when complications arise, such as abrupt vessel closure that might otherwise result in a patient requiring CABG. When we evaluated outcomes based on whether a patient received a stent the main findings of the analysis remained: ie, an increased risk of mortality at low-volume hospitals and an increased risk of CABG with low-volume physicians. Patients who received stents under the care of a low-volume physician had a slightly lower mortality risk. Stent use during a PCI, though, can be either planned or unplanned. Therefore, stent use during a PCI may be an outcome rather than a variable, and so these stratified analyses need to be interpreted with caution. However, the overall findings were consistent with a volume-outcome effect.

The patient population in our study reflects the national experience of Medicare patients, ie, an older, higher-risk group of patients. We are unable to comment on the national experience re-

**Table 4. Adjusted Rates for the Combined End Point of CABG or 30-Day Mortality Following PCI by Physician and Hospital Annual Medicare PCI Volume**

<table>
<thead>
<tr>
<th>Hospital Medicare PCI Volume per Year</th>
<th>Physician Medicare PCI Volume per Year</th>
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<tbody>
<tr>
<td>&lt;80</td>
<td>&lt;30</td>
</tr>
<tr>
<td>6.13</td>
<td>6.05</td>
</tr>
<tr>
<td>5.96</td>
<td></td>
</tr>
<tr>
<td>80-160</td>
<td>30-60</td>
</tr>
<tr>
<td>6.06</td>
<td>5.71</td>
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<tr>
<td>5.17</td>
<td></td>
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<tr>
<td>&gt;160</td>
<td>&gt;60</td>
</tr>
<tr>
<td>5.06</td>
<td>4.88</td>
</tr>
<tr>
<td>4.59</td>
<td></td>
</tr>
</tbody>
</table>

*All rates are percentages. CABG indicates coronary artery bypass graft; PCI, percutaneous coronary intervention. P trend across table, <.05. Adjusted for age, sex, race, acute myocardial infarction as primary diagnosis, comorbidity score, urgency of admission, and multivessel PCI.
garding the relationship between volume and outcome for the younger, lower-risk, non-Medicare patient population.

Although overall outcomes have improved in recent years, Medicare patients treated by high-volume physicians and high-volume centers continue to experience more favorable outcomes following PCIs. These findings support the current ACC recommendations regarding physician and hospital procedural volumes needed to maintain proficiency in PCIs. The question remains as to how patients, physicians, and hospitals will respond to these recommendations to ensure the highest quality of health care.

**Author Contributions:** Drs McGrath and Wennberg participated in study concept and design, acquisition of data, analysis and interpretation of data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, provided statistical expertise, and supervised conduct of the study. Drs Kellett and Ryan participated in analysis and interpretation of data, critical revision of the manuscript for important intellectual content, and supervised conduct of the study. Dr Malenka participated in study concept and design, analysis and interpretation of data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, and provided statistical expertise.

Ms Siewers and Dr Lucas participated in analysis and interpretation of data, critical revision of the manuscript for important intellectual content, and provided statistical expertise. Dr Malenka participated in study concept and design, analysis and interpretation of data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, and provided statistical expertise. Drs Kellett and Ryan participated in analysis and interpretation of data, critical revision of the manuscript for important intellectual content, and supervised conduct of the study.

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**REFERENCES**