Diagnostic-Therapeutic Cascade Revisited

Coronary Angiography, Coronary Artery Bypass Graft Surgery, and Percutaneous Coronary Intervention in the Modern Era

F.L. Lucas, PhD; A.E. Siewers, MPH; D.J. Malenka, MD; D.E. Wennberg, MD, MPH

Background—There is wide geographic variation in the use of coronary revascularization in the United States. Rates are closely related to rates of coronary angiography. We assessed the relationship between coronary angiography and coronary artery revascularization by procedure type (coronary artery bypass graft surgery or percutaneous coronary intervention).

Methods and Results—Using Part B claims for a 20% sample of the Medicare population, we calculated population-based rates of testing and treatment by region, using events identified in Part B claims as the numerator and the total number of Medicare beneficiaries residing in the area as the denominator and adjusting for regional differences in demographic characteristics with the indirect method. Cardiac catheterization rates varied substantially across regions, from 16 to 77 per 1000 Medicare beneficiaries. The relationship between coronary angiography rates and total coronary revascularization rates was strong ($R^2=0.84$). However, there was only a modest association between coronary angiography rates and coronary artery bypass graft surgery rates ($R^2=0.41$) with the suggestion of a threshold effect. The association between coronary angiography rates and percutaneous coronary intervention rates was strong ($R^2=0.78$) and linear.

Conclusions—The diagnostic-therapeutic cascade for coronary artery disease differs by therapeutic intervention. For coronary artery bypass graft surgery, the relationship is modest, and there appears to be a testing threshold beyond which additional tests do not result in additional surgeries. For percutaneous coronary intervention, the relationship is very tight, and no threshold appears to exist. Given the results of recent studies of medical versus invasive management of stable coronary disease, patients living in high-diagnostic-intensity regions may be getting more treatment than they want or need. (Circulation. 2008;118:2797-2802.)

Key Words: angiography ■ coronary disease ■ revascularization

Wide geographic variation exists in the use of coronary artery revascularization across the United States. Population-based rates of coronary artery bypass graft surgery (CABG) in the Medicare population vary nearly 5-fold, and rates of percutaneous coronary interventions (PCI) vary >6-fold. The wide variation in rates is not explained by differences in demographic characteristics or disease prevalence as measured by acute myocardial infarction rate. However, the rates of revascularization are highly correlated with rates of coronary angiography; we found that, in the Medicare population in 1996, the correlation between coronary angiography and revascularization was 0.93 ($R^2=0.87$) and that the relationship appeared to be almost perfectly linear.

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What might drive rates of coronary angiography? Generally, there is a correlation between the capacity to perform the diagnostic test and the likelihood that a test will be performed. There are moderate correlations between the population-based supply of cardiac catheterization laboratories and the supply of invasive and interventionalist cardiologists and the coronary angiography rate. Looking further upstream, we see that populations living in regions where more imaging stress tests are performed are also more likely to undergo coronary angiography. This finding of a tight linkage between the diagnostic test and the therapeutic intervention has been called the diagnostic-therapeutic cascade.

Previous investigations of the diagnostic-therapeutic cascade for coronary disease have considered the overall rate of revascularization and have not examined the relationship between coronary angiography and CABG separately from the relationship between coronary angiography and PCI. Since these studies were performed, however, the population-
based rates of CABG have decreased substantially while those of PCI have continued to increase. The present article first evaluates whether a tight relationship between diagnostic and therapeutic intensity still exists and then evaluates this relationship separately for the 2 intervention alternatives.

Methods

We used Medicare Part B (physician and supplier) claims data for a 20% random sample of Medicare beneficiaries to identify coronary angiography and revascularization procedures occurring during 2005. Procedures were defined using the appropriate current procedural terminology codes (CABG: 33510 to 33536; PCI: 92980 to 92984 and 92995 to 92996; coronary angiography: 93508 to 93529, 93539 to 93540, and 93545). The Part B file is a line item file, potentially containing >1 line item and associated current procedural terminology code for each procedure. We defined a procedure as any line item containing a current procedural terminology code of interest and counted only 1 procedure of each type for each person per day, identified with a unique patient identification code and covered date. If a single individual had, for instance, PCI and CABG on the same day, both would be counted. If an individual had 2 PCIs on different days, both would be counted. If an individual had 2 PCIs on the same day, we would count only 1 because we could not distinguish between 2 procedures or a single procedure using >1 PCI code. We added together all procedures of a given type to define the numerators of population-based rates.

We used the Medicare Denominator file to identify all beneficiaries eligible for Part B at midyear 2005 (~5.4 million beneficiaries). Because not all managed care plans submitted claims during this time period, we excluded beneficiaries who were enrolled in managed care plans (~17% of the total Part B population). The count of these individuals eligible for Part B and not managed care enrolled on June 30, 2005, defined the denominators of population-based rates.

Both the Part B and Denominator files contain beneficiary age, sex, race, and ZIP code of residence. Each beneficiary was assigned to a hospital referral region (HRR) based on her/his ZIP code of residence. HRRs are small geographic areas representing referral patterns for tertiary care, including cardiac surgery. To account for differences in the distribution of important demographic variables across HRRs, we calculated the adjusted rates of coronary angiography, total revascularization, CABG, and PCI for each HRR by dividing the number of events by the total number of beneficiaries and standardizing to the age/sex/race distribution of the total Medicare population with the indirect method. This method calculates the number of events that would be expected to occur in each HRR if the national (standard population) age/sex/race rates applied; the observed number of events is then divided by the expected number of events, and the resulting O/E ratio is multiplied by the national rate (standard population rate) to produce the adjusted rate.

We used weighted least-squares regression methods, weighting by the inverse of the variance, to assess the relationship between rates of coronary angiography and rates of revascularization, assessing departures from linearity by introducing squared, logarithmic, and inverse terms into regression models. Because the models containing squared terms fit best, these are the results we report here. We tested the final models for heteroscedasticity and independence of errors using graphical methods and a formal statistical test of model specification. There were 2 extreme outliers that distorted the relationship between coronary angiography rates and rates of PCI; to be conservative, we report the regression model results with these outliers deleted. We report the strength of the relationship between coronary angiography and revascularization rates using the $R^2$ statistic; this statistic can be interpreted as the proportion of variation in revascularization rates explained by variation in coronary angiography rates.

The Institutional Review Board at Maine Medical Center approved this study. The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Results

Table 1 gives the demographic characteristics of the study sample of ~5.4 million Medicare beneficiaries and the characteristics of those receiving one of the procedures of interest. Although 13% of the study population was ≥85 years of age, only 7% of those receiving cardiac catheterization were in the oldest age group; rates of PCI were much higher than rates of CABG in all groups but proportionately even higher in older patients, women, and black patients than in their comparator groups. For example, although there are 12.3 PCIs for each 4.7 CABGs in the youngest patients 65 to 69 years of age, a ratio of 2.6, there are 7.9 PCIs for each 1.6 CABGs in the oldest age group, a ratio of 4.9.

Coronary angiography rates were highly variable across HRRs, with a mean rate of 37.2 procedures per 1000 and a range of 16.2 to 77.0 per 1000 Medicare beneficiaries (Figure 1). CABG was also variable, with a mean of 4.9 procedures per 1000 Medicare beneficiaries and rates varying by a factor of 9 (range, 1.1 to 10.1). PCI was performed much more frequently, with a mean of 13.2 procedures per 1000 beneficiaries, and varied by a factor of nearly 11 (range, 4.2 to 44.7).

Coronary angiography rates were highly positively associated with revascularization rates ($R^2=0.84$; Figure 2). The relationship was positive with some suggestion of a flattening of the regression line at higher angiography rates (negative squared term coefficient, $P=0.02$).

Considering CABG and PCI separately, the relationships were quite different. Angiography rates were only modestly associated with CABG rates ($R^2=0.41$; Figure 3). The relationship had a modest slope at lower angiography rates; however, there was a suggestion of a threshold effect in that increasing angiography rates beyond 50 procedures per 1000 beneficiaries yielded much smaller increases in CABG rates (negative squared term coefficient, $P<0.0001$). The relationship between angiography rates and PCI rates was much stronger and linear ($R^2=0.78$; Figure 3). See Table I of the online Data Supplement for all model details.

Table 2 give estimated results from the final models. On average, an increase from 20 to 30 per 1000 in the coronary angiography rate resulted in an estimated increase of 4.6 per 1000 in the revascularization rate; an increase from 60 to 70 in the angiography rate resulted in an increase of 3.3 in the revascularization rate. For CABG, in areas with low angiography rates, each increase of 10 per 1000 in the angiography rate resulted in an increase of ~1 per 1000 in the CABG rate, whereas at higher angiography rates, the estimated CABG rate increased much less if at all; the increase from 60 to 70 resulted in no increase in CABG rate. However, an increase of 10 in the coronary angiography rate was associated with an estimated increase of 3.4 in the PCI rate regardless of the angiography rate.

Discussion

Coronary angiography rates were strongly correlated with population-based rates of revascularization. However, when coronary angiography is compared individually with the 2 intervention options, very different patterns emerged. Compared with the modestly sloped coronary angiography–CABG relationship with a suggestion of a threshold effect,
the coronary angiography–PCI relationship was steep and linear.

The simple explanation for the tight relationship between coronary angiography and overall revascularization rates is that there is a large reservoir of undiagnosed coronary artery disease, more of which is discovered in areas with higher coronary angiography rates. However, we have previously shown that rates of hospitalization for acute myocardial infarction are not correlated with revascularization rates (R²/H11005 0.03).3 The different relationship between angiography and PCI versus CABG further suggests that disease burden alone is unlikely to be the primary factor explaining these findings. Coronary disease burden could explain these relationships only if there are extremely different distributions of coronary artery disease severity and anatomy between populations that are unaccounted for by age, sex, and race.

Indications for CABG are fairly specific.12,13 Most studies suggest that CABG is currently performed for combinations of anatomy and function for which surgical revascularization improves long-term survival, at least compared with older medical therapy, or for patients with multivessel disease to relieve symptoms and improve quality of life. The modest relationship between angiography and CABG suggests that although more cases are found for surgical intervention as coronary angiography rates increase, beyond a certain point, increasing rates do not identify additional patients for whom CABG is the preferred intervention. However, the picture for PCI is quite different. There is a much more positive relationship between coronary angiography and PCI rates, and there is no place on the coronary angiography/PCI curve that suggests that all patients with lesions that could undergo a PCI have been identified. What accounts for the apparent lack of a threshold for intervention with a catheter?

When we look for coronary artery disease in an elderly population, we find it. However, the coronary angiography–CABG relationship suggests that the “marginal yield” of severe coronary artery disease falls with higher rates of coronary angiography. Therefore, it appears that the marginal disease found at very high rates of angiography is predomi-
nantly nonsurgical 1- and 2-vessel disease. Unlike CABG, there are almost no absolute indications for PCI,\textsuperscript{14} the exception being primary PCI for acute myocardial infarction. Thus, it must be patient and/or physician preferences for PCI over medical management that drive the tight diagnostic-therapeutic relationship for PCI.

The existing limited data suggest that patient and physician preferences for treatment of coronary artery disease may be in conflict. Only 1 randomized trial of patient preferences for the treatment of coronary artery disease has been performed.\textsuperscript{15} In this study, patients on the waiting list for revascularization in Ontario, Canada, a geographic region that had lower rates of intervention than any HRR in the United States, were randomized to usual care versus an interactive decision aid designed to assist patients in making complex medical decisions. Patients in the decision aid arm

Figure 2. Relationship between coronary angiography rates and revascularization rates by HRR, Medicare, 2005 (estimated regression line and 95% CI).

Figure 3. Relationship between coronary angiography rates and revascularization rates by procedure type, Medicare, 2005 (estimated regression line and 95% CI).
Table 2. Estimated Revascularization Rates Associated With Coronary Angiography Rates*

<table>
<thead>
<tr>
<th>Coronary Angiography Rate</th>
<th>Estimated Revascularization Rate (95% CI)</th>
<th>Estimated CABG Rate (95% CI)</th>
<th>Estimated PCI Rate (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>10.2 (9.7–10.7)</td>
<td>2.9 (2.6–3.2)</td>
<td>7.0 (6.6–7.3)</td>
</tr>
<tr>
<td>30</td>
<td>14.8 (14.6–15.1)</td>
<td>4.2 (4.0–4.3)</td>
<td>10.4 (10.2–10.6)</td>
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<td>40</td>
<td>19.1 (18.9–19.4)</td>
<td>5.1 (4.9–5.2)</td>
<td>13.8 (13.6–14.0)</td>
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<tr>
<td>50</td>
<td>23.0 (22.7–23.4)</td>
<td>5.6 (5.4–5.8)</td>
<td>17.2 (16.8–17.6)</td>
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<tr>
<td>60</td>
<td>26.6 (25.9–27.4)</td>
<td>5.8 (5.4–6.2)</td>
<td>20.6 (20.1–21.2)</td>
</tr>
<tr>
<td>70</td>
<td>29.9 (28.3–31.4)</td>
<td>5.7 (4.9–6.5)</td>
<td>24.0 (23.3–24.8)</td>
</tr>
</tbody>
</table>

*Results of best-fit regression models. Population-based rates are expressed per 1000 Medicare beneficiaries.

were 28% more likely to choose medical treatment over either PCI or CABG than those in the control arm. Lin and colleagues16 found that cardiologists, despite acknowledging the lack of evidence of mortality and acute myocardial infarction prevention benefit, stated that they would provide PCI for minor lesions unrelated to symptoms. The authors (and the cardiologists interviewed) attributed these findings to the occultostenotic reflex, the impulse to fix a stenosis even if it is unlikely to cause future problems. Cardiologists also reported a bias toward intervention because of a belief, despite evidence,18–21 that an open artery provided benefit and because of concerns about regret if they failed to act and a patient suffered a subsequent event. Combined, these studies suggest that patients with coronary artery disease may be more risk averse than cardiologists when considering treatment options.

Other factors also may play a role in the tight, linear relationship between angiography and PCI. Often, the same cardiologist is both diagnostician and interventionalist. Potential issues related to self-referral are compounded by clinically significant intraobserver and interobserver variability in interpretation of angiograms20 and the need to make rapid, rather than measured, decisions on whether and where to intervene. This propensity to intervene has been given a clear push by private insurers. Since the early 1990s, insurance companies have encouraged the use of ad hoc angioplasty through explicit payment policies that discourage staged procedures, a diagnostic event followed by an interventional event. This policy may have made sense from the standpoint of reducing episode-based costs; however, it may have had the unanticipated consequence of increasing the numbers of PCIs performed.

Our study has some limitations. First, we limited our analysis to the aged Medicare population. However, we have no reason to believe that patterns of care across geographic regions vary systematically by age or insurance status. Variation in Medicare rates is reflected in younger populations (www.bcbsm.com/atlas2). We are unable to assess the indication for testing, results of the coronary angiography, and indications for revascularization. However, this is an important limitation only if disease patterns vary remarkably across geographic areas, and we have previously found little evidence of large disparities in disease distribution across geographic regions.3

The tight relationship between diagnostic intensity and therapeutic intensity with PCI raises a fundamental challenge to those managing patients with coronary artery disease. There is established evidence of benefit of PCI in unstable coronary syndromes,22 and current guidelines recommend such a strategy in these patients.23 However, several recent studies have suggested that patients with stable coronary disease who undergo PCI may receive no marginal benefit or, worse, face increased risk of death and acute myocardial infarction compared with those managed medically.24–26

We would contend that unstable patients are more likely to receive intervention no matter where they live, but the marginal patients in high-rate areas are likely to be those who are less symptomatic in whom the benefit is much less well defined. Our models suggest that, in areas with high rates of coronary angiography, at most 0.2 patients with serious coronary anatomy eligible for CABG would be identified for each 10 angiograms performed. Thus, the cost of, at most, 0.2 appropriate CABGs would be 10 additional angiograms and 3.4 additional PCIs. Given the diagnostic-therapeutic yield, a fundamental question needs to be asked: In the low- and moderate-risk patient, do we even want to know the anatomy?

Sources of Funding

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Disclosures

Dr Malenka reports receiving research funding from Guidant Endovascular Systems. The other authors report no conflicts.

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2. Hannan EL, Chuntao W, Chassin MR. Differences in per capita rates of revascularization and in choice of revascularization procedure for eleven states. BMC Health Serv Res. 2006;6:35.


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**CLINICAL PERSPECTIVE**

Wide variability exists in rates of coronary angiography, depending on geographic location. Although there is a strong relationship between rates of angiography and revascularization, the relationship is different depending on revascularization modality. With the geographic area as the unit of analysis, regression models indicate that coronary artery bypass rates are much less closely related to angiography rates than are percutaneous coronary intervention rates. In addition, there is a suggestion of a threshold effect for coronary artery bypass graft surgery in that areas with the highest angiography rates do no more coronary artery bypass graft surgeries than areas with more modest rates. Percutaneous coronary intervention rates, however, increase even at the very highest angiography rates. We conclude that, in very-high-rate areas, little or no additional serious coronary anatomy amenable to coronary artery bypass graft surgery is identified. Because routine use of percutaneous coronary intervention provides a known mortality and acute myocardial infarction prevention benefit only in patients with unstable coronary syndromes and because patients with unstable symptoms are likely to reach the catheterization laboratory no matter where they live, we are concerned that patients with a lower chance to benefit may be undergoing percutaneous coronary intervention in these areas of very high catheterization rates.
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Appendix

Appendix Table 1. Model Details: Best fit model after removal of two HRRs with extremely high cardiac catheterization rates

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Model Term</th>
<th>Beta coefficient</th>
<th>Standard Error</th>
<th>R²</th>
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<td>1.0806</td>
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<td>Cath rate</td>
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<td>Cath rate²</td>
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<td>0.0007</td>
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<td>CABG rate</td>
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<td>0.5933</td>
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<td>Cath rate</td>
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<td>PCI rate</td>
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<td>0.3693</td>
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<tr>
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<td>Cath rate</td>
<td>0.3409</td>
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