Twenty-Year Evolution of Percutaneous Coronary Intervention and Its Impact on Clinical Outcomes


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Background—Percutaneous coronary intervention (PCI) has undergone rapid progress, both in technology and adjunct therapy. However, documentation of long-term temporal trends in relation to contemporary practice is lacking.

Methods and Results—We analyzed PCI use and outcomes in 8976 consecutive patients in the multicenter, National Heart, Lung, and Blood Institute–sponsored 1985–1986 percutaneous transluminal coronary angioplasty (PTCA) and 1997–2006 Dynamic Registries waves (wave 1: 1997–1998, bare-metal stents; wave 2: 1999, uniform use of stents; wave 3: 2001–2002, brachytherapy; waves 4 and 5: 2004–2006, drug-eluting stents). Patients undergoing PCI in the recent waves were older and more often reported comorbidities than those in the balloon era. PCI was more often performed for acute coronary syndromes and, in spite of the greater disease burden, was more often selective. Procedural success was achieved and maintained more often in the stent era. Significant reductions were observed in in-hospital rates (%) of myocardial infarction (PTCA Registry: 4.9; wave 1, 2.7; wave 2, 2.8; wave 3, 1.9; wave 4, 2.6; wave 5, 2; \( P_{\text{trend}}<0.001 \)) and emergency coronary artery bypass surgery (PTCA Registry: 3.7; wave 1, 0.4; wave 2, 0.4; wave 3, 0.3; wave 4, 0.4; wave 5, 0; \( P_{\text{trend}}<0.001 \)). Compared with the PTCA Registry, risk for repeat revascularization (31 to 365 days after index PCI) was significantly lower in the dynamic waves (adjusted hazard ratio: wave 1, 0.72; wave 2, 0.51; wave 3, 0.51; wave 4, 0.30; wave 5, 0.36; \( P<0.05 \) for all).

Conclusions—Percutaneous interventions, in the last 2 decades, have evolved to include more urgent, comorbid cases, despite achieving high success rates with significantly reduced need for repeat revascularization. (Circ Cardiovasc Intervent. 2009;2:6-13.)

Key Words: percutaneously coronary intervention | temporal trend | registries

Percutaneous coronary intervention (PCI) was first performed in 1977 and since then has gained rapid acceptance as a treatment option for coronary artery disease. The field has witnessed rapid technological advancements with a parallel progress in adjunct and secondary pharmacological therapy. Concomitantly, the profile of patients (and lesions) undergoing PCI has become heterogeneous to the extent that it now often includes “off-label” or “untested” circumstances. As a result, in spite of the dramatic reduction in the need for repeat procedures, questions regarding the safety and appropriate utilization of the procedure have emerged. A time-sensitive appraisal of PCI use and outcomes is thus warranted to place these concerns in a historical perspective. Prior studies of temporal trends in PCI were conducted in early technology eras, or based on single-center experience. Our objectives, therefore, are to document long-term trends in patient and procedural characteristics, and to compare procedural outcomes using data from the multicenter, National Heart, Lung, and Blood Institute–sponsored percutaneous transluminal coronary angioplasty (PTCA) and Dynamic Registries. Taken together, these registries span 2 decades of clinical practice in North America and as such, range from the balloon angioplasty era to contemporary use of drug-eluting stents.

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Results

Patient and Procedural Characteristics

Consecutive patients undergoing PCI in the recent waves were older (mean age in years, from older to more recent cohorts: 58, 62, 63, 64, 64, 64; \( P_{\text{trend}} < 0.001 \)) and more often women (women from older to more recent cohorts: 26, 32, 32, 35, 31, 33; \( P_{\text{trend}} < 0.001 \)) when compared with the PTCA Registry. Additionally, more patients in the Dynamic waves reported concomitant comorbidities (hypertension, diabetes, and severe noncardiac conditions) and prior bypass surgery (Table 1). Acute coronary syndrome (unstable angina or acute MI, which includes both ST-segment elevation and non-ST segment elevation MI) remained the most common reason for revascularization over time, with a concomitant rise in nonselective procedures. Baseline disease burden, as reflected by mean number of lesions and vessels diseased, was greater in the Dynamic Registry. Procedural attempts, on the other hand, more often involved single vessels and lesions, both in the overall cohort (Table 2) and specifically in the setting of multivessel disease (Table 3). The profile of attempted lesions was more severe in the Dynamic Registry with increased attempts on calcified lesions (% from older to more recent cohorts: 11, 30, 27, 24, 27, 33; \( P_{\text{trend}} < 0.001 \)) and thrombotic lesions (from older to more recent cohorts: 14, 27, 30, 21, 21, 22; \( P_{\text{trend}} < 0.001 \)); this pattern persisted even within the Dynamic Registry with increased attempts on Type C lesions (wave 1, 20%; wave 2, 16%; wave 3, 19%; wave 4, 22%; wave 5, 30%; \( P_{\text{trend}} < 0.001 \)).

Use of stents, either alone or in conjunction with balloons, increased from 70% in wave 1 (only bare metal) to 97% in wave 5. Use of drug-eluting stents (DES), introduced in wave 4, increased from 71% to 88% in wave 5; atherecomy and brachytherapy were used in fewer than 2% of patients. Procedural use of glycoprotein IIb/IIIa inhibitors increased from 25% in wave 1 to 55% in wave 3 to then dip to 41% in wave 5, coinciding with the introduction of bivalirudin. Procedural use of ticlopidine/clopidogrel increased from 52% in wave 1 to 83% in wave 5 (\( P_{\text{trend}} < 0.001 \)).

In-Hospital Outcomes

Total angiographic and procedural success were achieved and maintained more often in the Dynamic Registry (Table 4). Rates of in-hospital MI (from older to more recent cohorts: 4.9%, 2.7%, 2.8%, 1.9%, 2.6%, 2.0%; \( P_{\text{trend}} < 0.001 \)) and emergency CABG (from older to more recent cohorts: 3.7%, 0.4%, 0.4%, 0.3%, 0.4%, 0.0%; \( P_{\text{trend}} < 0.001 \)) were significantly lower in the more recent waves. On the other hand, compared with the PTCA Registry, in-hospital mortality rates were marginally higher in most of the recent waves with the exception of wave 5 (from older to more recent cohorts: 1.4%, 1.9%, 1.8%, 1.3%, 2.0%, 0.7%; \( P_{\text{trend}} > 0.34 \); probability value for wave 4 versus wave 5: 0.01). Mean duration of hospital stay (days) decreased over time (from older to more recent cohorts: 4.0, 2.7, 2.6, 2.4, 2.2, 2.0; \( P_{\text{trend}} < 0.001 \)). Discharge use of recommended secondary pharmacological therapy (aspirin, \( \beta \)-blockers, lipid-lowering therapy, antiplatelet agents) increased significantly across the waves (Table 4).
Early (<30 Days) and Late (31 to 365 Days) Follow-Up Events

Cumulative unadjusted mortality rates over 1 year were higher in the Dynamic Registry waves, when compared with the PTCA Registry in the overall cohort (Figure 1). This pattern persisted in patients undergoing PCI for both stable angina (from older to recent waves: 2.2%, 3.2%, 3.7%, 1.0%, 4.8%, 4.9%; \(P_{\text{log rank}} = 0.06\)) as well as acute coronary syndromes (from older to recent waves: 4.2%, 6.0%, 5.7%, 5.2%, 5.7%, 4.3%; \(P_{\text{log rank}} = 0.23\)). Risk of mortality was assessed both within and after 30 days following index PCI for the Dynamic Registry waves, using PTCA Registry as reference. The adjusted risk of mortality in the Dynamic waves was nonsignificantly lower when compared with the PTCA Registry in both follow-up periods (Figure 2). The adjusted risk for death/MI, on the other hand, reached statistical signifi-

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<td>26</td>
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<td>Circumstance of index PCI, %</td>
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BMI indicated body mass index; CHF, congestive heart failure; EF, ejection fracture; CAD, coronary artery disease; n/a, data not available.

*\(P_{\text{trend}}\) in characteristics across the cohort: Cochran Armitage test for 2-level categories and Jonckheere-Terpsta test for continuous variables and nominal/ordinal categories.
cance for some recent waves when compared with the PTCA registry (Figure 2A and 2B).

The overall rates of repeat revascularization (repeat PCI or CABG) over 1 year decreased substantially from 28% in the PTCA Registry to 11% in wave 5 \((P\text{log rank}/H110210.001)\). However, reduction in early CABG rates was initially steep and followed by a plateau in the stent era, whereas rates of late CABG successively reduced over time (Figure 3). On the other hand, cumulative rates of early repeat PCI, though small in number, increased, whereas the need for late repeat PCI


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<td>(N=1250)</td>
<td>(N=1210)</td>
<td>(N=1284)</td>
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<td>84</td>
<td>83</td>
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<td>7</td>
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<td>Lesions attempted, %</td>
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\(P_{\text{trend}}\) in characteristics across the cohorts assessed using the Jonckeheere-Terpsta test.
was significantly reduced across the cohorts. Adjusted risk for repeat revascularization (CABG or repeat PCI) was significantly lower for the Dynamic waves, when compared with the PTCA Registry, both in the early (hazard ratios [95% CI]: wave 1, 0.44 [0.32 to 0.60]; wave 2, 0.30 [0.21 to 0.45]; wave 3, 0.27 [0.18 to 0.41]; wave 4, 0.36 [0.26 to 0.52]; wave 5, 0.26 [0.18 to 0.39]; P < 0.05 for all) as well as late follow-up periods (hazard ratios [95% CI]: wave 1, 0.72 [0.61 to 0.85]; wave 2, 0.51 [0.42 to 0.63]; wave 3, 0.51 [0.41 to 0.62]; wave 4, 0.30 [0.24 to 0.38]; wave 5, 0.36 [0.28 to 0.45]; P < 0.05 for all) (also see Supplemental Figure).

**Discussion**

Angioplasty, when introduced in 1977, relied solely on balloons for dilatation of coronary arteries. Although this in itself revolutionized the treatment of coronary artery disease, the advent of BMS caused a drastic expansion in the type of patients undergoing the procedure. However, as problems of in-stent restenosis soon became apparent, alternative techniques including atherectomy and brachytherapy were introduced, only to be followed by the more successful drug-eluting stents. Our report provides a snapshot of this evolution and its impact on procedural outcomes over a 20-year period in 2 large, prospective, multicenter registries of clinical practice in North America. These findings are especially noteworthy given that previous reports of temporal trends have been restricted to specific technology eras or are single-center experiences.

PCI use in contemporary practice has expanded to include more patients with severe comorbidities, acute coronary syndromes, and multivessel disease. The lower rates of prior MI in the more recent waves, especially in light of the concomitant trend of higher rates of PCI performed for acute coronary syndromes over time, is noteworthy. Although these trends could potentially be a reflection of the revised guidelines favoring primary PCI instead of fibrinolysis in acute syndromes, they are also in keeping with the reported decline in annual rates of recurrent infarctions in community-based settings. Attempted lesions, in the recent waves, were more often determined to be calcified or thrombotic, when compared with the early cohorts. These trends, however, could be a reflection of improved or better imaging techniques over time, rather than a true increase in these characteristics. The concept of complete revascularization, which stemmed from

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<tbody>
<tr>
<td>Total angiographic success</td>
<td>74</td>
<td>93</td>
<td>93</td>
<td>94</td>
<td>95</td>
<td>96</td>
<td>&lt;0.001</td>
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<tr>
<td>Procedural success</td>
<td>82</td>
<td>94</td>
<td>95</td>
<td>96</td>
<td>96</td>
<td>97</td>
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<tr>
<td>Death</td>
<td>1.4</td>
<td>1.9</td>
<td>1.8</td>
<td>1.3</td>
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<td>0.34</td>
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<td>Myocardial Infarction</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Bypass surgery</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Major entry site complications</td>
<td>...</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>&lt;0.001</td>
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<tr>
<td>Discharge medication use (among those alive), %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>ACE inhibitor</td>
<td>1</td>
<td>29</td>
<td>37</td>
<td>45</td>
<td>54</td>
<td>50</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Aspirin</td>
<td>84</td>
<td>94</td>
<td>94</td>
<td>95</td>
<td>97</td>
<td>98</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(\beta)-blocker</td>
<td>26</td>
<td>66</td>
<td>72</td>
<td>77</td>
<td>81</td>
<td>81</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Calcium channel blocker</td>
<td>78</td>
<td>30</td>
<td>21</td>
<td>17</td>
<td>14</td>
<td>13</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lipid lowering agents</td>
<td>1</td>
<td>39</td>
<td>58</td>
<td>73</td>
<td>86</td>
<td>88</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Digitalis</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diuretics</td>
<td>6</td>
<td>15</td>
<td>18</td>
<td>20</td>
<td>24</td>
<td>22</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Long-acting nitrates</td>
<td>34</td>
<td>33</td>
<td>27</td>
<td>21</td>
<td>13</td>
<td>10</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ticlopidine</td>
<td>...</td>
<td>70</td>
<td>23</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Clopidogrel</td>
<td>...</td>
<td>...</td>
<td>61</td>
<td>92</td>
<td>95</td>
<td>97</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Warfarin</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Lesion-Level**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Major dissection, %</td>
<td>3</td>
<td>12</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Abrupt closure in lab, %</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Side branch occlusion, %</td>
<td>0.4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0.08</td>
</tr>
</tbody>
</table>

ACE indicates angiotensin-converting enzyme.

\(P_{trend}\) in characteristics across the cohorts, assessed using Cochran-Armitage test for dichotomous variables and Jonckheere-Terpsta test for continuous variables and nominal/ordinal categories.
early CABG studies, appears to have given way to a more
selective approach over time as evidenced by the predomi-
nance of single-vessel attempts in multivessel disease pa-
tients. One plausible explanation is the greater use of PCI for
acute conditions where functional (and not anatomic) revas-
cularization is of priority. A prior report from this Registry has also shown that patients with multivessel disease, in
whom complete revascularization was unachievable, were
older with more comorbidities and lower ejection fraction,
when compared with those in whom complete revascularization was achieved or selective revascularization was the
method of choice.

Temporal Trends in Procedural Safety
The present report demonstrates a dramatic improvement in
procedural outcomes (high success rates and reduced need for
in-hospital bypass surgery) with the advent of stents. Further-

Figure 1. Cumulative (Kaplan–Meier) event rates for death and death/MI in the NHLBI-sponsored PTCA (1985–1986) and Dynamic (1997–2006) Registries at 1 year.

Figure 2. Adjusted hazard ratios (95% confidence intervals) for death and death/MI in the 1997–2006 Dynamic Registry waves (reference: 1985–1986 PTCA Registry).

Figure 3. Cumulative (Kaplan–Meier) event rates for early (≤ 30 days) and late (31 to 365 days) CABG. A, Repeated PCI; B, NHLBI-sponsored PTCA (1985–1986) and Dynamic (1997–2006) Registries.
more, even within the stent era, there is a significant reduction in the initially high rates of dissections and abrupt closures. Although this certainly reflects the huge impact of technology, it also underscores the importance of operator training and better techniques. Improvements in in-hospital outcomes are also seen to extend over 1 year (lower rates of death/MI and CABG) and are congruent with previously published reports. Nonetheless, the higher crude mortality rates in the Dynamic Registry, in the overall cohort and by primary indication, is reflective of sicker profile (older patients, more comorbidities, greater disease burden) of patients enrolled in these waves. Prior comparison of 1-year outcomes between patients undergoing PCI for stable versus unstable angina showed little change in mortality rates in the latter cohort over the past 16 years. In another report of 2839 patients with complex lesions (defined as a lesion showing evidence of thrombus, calcification, bifurcation or ostial location, or chronic occlusion), both in-hospital and 1-year mortality rates were higher, compared with attempts on simpler lesions. Moreover, reports of stent-thrombosis with DES use has led to concerns of use and timing of dual antiplatelet therapy and the need to focus on cause-specific, rather than overall, mortality. Thus, in spite of the marked overall improvement in the field, certain high-risk subsets continue to pose major challenges and warrant closer attention.

Temporal Trends in Effectiveness
Development of devices in PCI was primarily aimed at reducing the need for repeat interventions, be it surgical or percutaneous. Our cohorts are representative of key devices available in the respective time periods: PTCA Registry (balloons), wave 1 (early use of BMS), wave 2 (uniform use of BMS), wave 3 (brachytherapy), wave 4 (early use of DES), and wave 5 (established use of DES). The sustained reduction in the need for repeat revascularization, therefore, truly underscores the progress made in the field. The greater need for “early” repeat PCI paralleling the precipitous drop in CABG rates, small sample size notwithstanding, deserves particular mention. We believe that while in the present era, CABG was a more powerful option in the event of failed index PCIs, the advent of stents caused a shift in favor of using PCI for repeat revascularization in these cases. Alternatively, PCI has been increasingly performed in sicker patients with multivessel disease but using a selective treatment strategy while achieving 100% procedural success (see Supplemental Table). The increased use of early PCI, therefore, may be a related fall out of this greater disease burden.

Secondary Medical Therapy in PCI
Pharmacological therapy in atherosclerosis has undergone major improvements over time and their salutary effects in the setting of coronary revascularization have been well documented. More recently, a comparison of an initial strategy of PCI and optimal medical therapy versus medical therapy alone, in 2287 patients with stable coronary artery disease, revealed no difference in the rates of the composite end point of death and nonfatal MI. Although this highlights the notable progress in the field of medical therapy, it also reiterates the need for systemic management of atherosclerotic disease. After all, PCI treats only angiographically visible stenoses and not the underlying disease mechanism responsible for new lesions and resultant ischemic events. To this end, the increase in the discharge use of evidence-based therapy (aspirin, \( \beta \)-blockers, cholesterol-lowering agents, and antiplatelet therapy), as observed in our report, is encouraging and reflects an improved awareness of the importance of secondary prevention.

Limitations
Although limitations inherent to use of a registry database must be acknowledged, enrollment of consecutive patients with no exclusion criteria permits representation of real world practice and allows for the timely evaluation of safety and effectiveness. The majority of centers participating in the registries were medium to high-volume hospitals and more often academic centers, thus limiting the generalizability of our findings. The primary objective of this analysis was to assess temporal trends using the “wave” variable as a marker of change in both technology as well as secondary therapy in that particular time period. Therefore, we did not specifically adjust for or evaluate these factors in multivariable models. Also, ascertainment of data was refined in each wave to incorporate prevailing concerns in the field. Thus, only those variables available in all cohorts were considered for multivariable analysis. Information on periprocedural myocardial enzymes was lacking in both the registries, thus, limiting our ability to assess related impact on events.

Conclusions
Our report from the large, prospective, multicenter, NHLBI-sponsored 1985–1986 PTCA (balloon era) and 1997–2006 Dynamic Registries (BMS and DES era) documents the rapid evolution in PCI as a treatment option for atherosclerosis. PCI use, over time, has expanded to include more patients with severe comorbidities, acute coronary syndromes and complex, multivessel disease. However, in spite of the sicker patient profile and greater disease burden at baseline, procedural success was achieved more often and with significant reductions in immediate (in-hospital rates of MI and emergency CABG) as well as 1-year (reduced need for repeat procedures) outcomes. Further studies, however, are warranted to elucidate the impact, or lack thereof, of PCI on long-term mortality.

Sources of Funding
This study was supported by grants (HL-33292-14 through HL-33292-22 from the NHLBI (Bethesda, Md).

Disclosures
Dr Wilensky received grant support from Boston Scientific and has ownership interests in Johnson & Johnson. Dr Williams received grant support from Cordis Corporation, Boston Scientific, and Abbott Vascular and serves on the consultant/advisory board for Cordis Corporation.

References


**CLINICAL PERSPECTIVE**

We analyzed temporal trends in the use of de novo percutaneous coronary intervention (PCI) and the associated in-hospital and 1-year outcomes in 8976 consecutive patients from the multicenter, National Heart, Lung, and Blood Institute-sponsored PTCA and Dynamic Registries [PTCA registry: 1985–1986, balloon angioplasty; Dynamic Registry wave 1: 1997–1998, bare-metal stents; wave 2: 1999, uniform use of stents; wave 3: 2001–2002, brachytherapy; waves 4 and 5: 2004–2006, drug-eluting stents]. PCI use, over time, has expanded to include more patients with severe comorbidities, acute coronary syndromes, and complex, multivessel disease. However, in spite of the sicker patient profile and greater disease burden at baseline, procedural success was achieved more often and with significant reductions in the in-hospital rates of myocardial infarction and emergency coronary artery bypass surgery. Considerable improvements were also observed in the use of secondary evidence-based pharmacological therapy after PCI. Multivariable analyses of outcomes over 1 year show significant, sustained reduction in the need for repeat revascularization but little impact on mortality. PCI, in the last 2 decades, has been increasingly applied to “sicker” patients and yet has achieved substantial improvements in procedural safety and effectiveness (reduced need for repeat procedures). Further studies are warranted to elucidate the impact, or lack thereof, of PCI on long-term mortality.
Lakshmi Venkitachalam, Kevin E. Kip, Faith Selzer, Robert L. Wilensky, James Slater, Suresh R. Mulukutla, Oscar C. Marroquin, Peter C. Block, David O. Williams and Sheryl F. Kelsey for the Investigators of NHLBI-Sponsored 19851986 PTCA and 19972006 Dynamic Registries

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SUPPLEMENTAL MATERIALS
SUPPLEMENTAL METHODS:

APPENDIX 1: Participating centers and personnel in the NHLBI-sponsored 1985-86 PTCA and 1997-2006 Dynamic Registries

1985-1986 PTCA Registry:

Program Office: National Heart, Lung, and Blood Institute (Bethesda, Maryland): Thomas Robertson.

1997-2006 NHLBI Dynamic Registry study:
Clinical Centers: Arizona Heart Institute - G. DorRos*, K. Murphy; Boston Medical Center (Boston, MA) - A. Jacobs*, D. Fine, S. Tressel; Cardiovascular Medicine Associates (Houston, TX) - M. Al-Bassam*, D. Lance; Emory University Hospital (Atlanta, GA) - S. King III* (former), J. Douglas*, P. Block*, P. Hyde, E. Block, E. Wright; Institute for Clinical and Experimental Medicine-IKEM (Prague) - V. Stanek*; Lankenau Hospital (Wynnewood, PA) - L. Bentivoglio*(former), P. Coady*, T. Shapiro, E. Tarthe, H. Criner, A.M. Chikowski; Lenox Hill Heart and Vascular Institute (New York, NY) - H. Cohen*, C. Brennan, M. Abenoja; Medical College of Virginia (Richmond, Virginia) - M. Cowley*, K. Hall, R. O'Brien; Montefiore Medical Center (Bronx, NY) - V.S. Srinivas*, M. Galvin; Montreal Heart Institute (Montreal, Canada) -
M.G. Bourassa*(former), S. Doucet*, J.-F. Tanguay*, S. Taillefer, L. Robillard, N. St-Jean; New York University Medical Center (New York, NY) - J. Slater*, E. Weisman, C. Wang; Piedmont Hospital–Fuqua Heart Center of Atlanta (Atlanta, GA) - S. King III*(former), W. Mashman*, J. Mattia, K. Shemwell, J. Creech; Providence-St. Vincent Medical Center (Portland, Oregon) - P. Block*(former), M. Vawter*, B. Block; Rhode Island Hospital (Providence, Rhode Island) - D. Williams*, D. Abbott, J. Muratori, T. Chaffee; Seton Medical Center (Daly City, California) - R. Myler*(former), R. Shaw*, F. Millhouse*, M. Murphy, M. Cavanaugh; St. Luke's-Roosevelt Hospital (New York) - J. Slater*, D. Tormey; St. Mary's Hospital–Mayo Clinic (Rochester, MN) - D. R. Holmes*, S. Brevig, R. Connelly, P. Sinning; University of Chicago (Chicago, IL) - D. Faxon*(former), E. Holper*(former), J. Lopez*, P. Bennett, C. Ball; University of Maryland Hospital (Maryland) - W. Laskey*(former), J.L. Stafford*, B. Reicher, D. Beach; University of New Mexico (Albuquerque, NM) - W. Laskey*, C. Wells; University of Pennsylvania Health System (Philadelphia, PA) — R. Wilensky*, R. Glaser, M. Walsh; University of Pittsburgh Medical Center–UPMC-Presbyterian University Hospital (Pittsburgh, PA) – H. Cohen*(former), O. Marroquin*, S. Mulukutla, D. Rosenfelder, C. Farrell, V. Iouchmanov, T. Vita, R. Rapsinski; University of Southern California (Los Angeles, CA) - D. Faxon*, W. Hill; Wake Forest University Medical Center (Winston-Salem, NC) - M. Kutcher*, T. Young. Data Coordinating Center- University of Pittsburgh (Pittsburgh): K.M. Detre* (deceased), S.F. Kelsey*, K.E. Kip*, F. Selzer, H. Vlachos, L. Venkitachalam, S. Lawlor, E. Passano; Program Office: National Heart, Lung, and Blood Institute (Bethesda, Maryland): G. Sopko, P. Desvigne-Nickens; S.Goldberg

* Principal Investigators
APPENDIX 2: List of covariates remaining in the final model after forcing ‘Wave’ variable, by type of endpoint

DEATH

Early (≤30 days of index PCI): Age ≥ 65 years, body mass index, history of comorbidities (diabetes, congestive heart failure, hypercholesterolemia, severe non-cardiac comorbidities), circumstances of index PCI (elective/urgent/emergent), multivessel disease, significant proximal LAD disease, attempts on total occlusions.

Late (31-365 days after index PCI): Age ≥ 65 years, body mass index, history of comorbidities (diabetes, congestive heart failure, severe non-cardiac comorbidities), smoking status, number of significant lesions at baseline

DEATH/MI

Early (≤30 days of index PCI): Age ≥ 65 years, body mass index, history of comorbidities (diabetes, congestive heart failure), circumstances of index PCI (elective/urgent/emergent), primary reason for index PCI, number of significant lesions at baseline, significant proximal LAD disease, number of vessels attempted, attempts on total occlusions or thrombotic lesions.

Late (31-365 days after index PCI): Age ≥ 65 years, body mass index, history of comorbidities (diabetes, congestive heart failure, severe non-cardiac comorbidities), number of significant lesions at baseline, number of lesions attempted, attempts on grafts or calcified lesions or lesions that receives collaterals

Non-staged Repeat PCI during a subsequent hospitalization

Early (≤30 days of index PCI): Body mass index, number of significant lesions at baseline, multivessel disease and circumstances of index PCI (elective/urgent/emergent).

Late (31-365 days after index PCI): Age ≥65 years, primary reason for revascularization, evidence of thrombus, number of lesions and vessels attempted;

Bypass surgery

Early (≤30 days of index PCI): Circumstances of index PCI (elective/urgent/emergent), History of bypass surgery, number of significant lesions at baseline, multivessel disease, significant
proximal LAD disease, occluded grafts, number of lesions attempted, attempts on total occlusions.

**Late** (31-365 days after index PCI): History of diabetes, multivessel disease, and significant proximal LAD disease

**Repeat PCI or bypass surgery**

**Early** (≤30 days of index PCI): Circumstances of index PCI (elective/urgent/emergent), primary reason for index PCI, multivessel disease, significant proximal LAD disease, and attempts on total occlusions

MVD, primary reason for revascularization, procedural circumstances, calcified lesion, total occlusion attempted, and proximal LAD lesion attempted;

**Late** (31-365 days after index PCI): Age ≥ 65 years, body mass index, history of diabetes or myocardial infarction, primary reason for index PCI, multivessel disease, significant proximal LAD disease, number of lesions attempted, attempts on thrombotic or graft lesions.
### SUPPLEMENTAL TABLE

Baseline characteristics of patients who underwent repeat PCI within 30 days of index procedure

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>PTCA Registry</th>
<th>Dynamic Registry</th>
<th>P*&lt;sub&gt;trend&lt;/sub&gt;</th>
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<tbody>
<tr>
<td>Mean baseline age</td>
<td>58.7</td>
<td>59.3</td>
<td>61.5</td>
</tr>
<tr>
<td>Prior MI, %</td>
<td>50</td>
<td>37.5</td>
<td>33.3</td>
</tr>
<tr>
<td>Severe non cardiac diseases, %</td>
<td>6.7</td>
<td>41.7</td>
<td>50</td>
</tr>
<tr>
<td>History of Diabetes, %</td>
<td>5.6</td>
<td>29.2</td>
<td>16.7</td>
</tr>
<tr>
<td>History of Hypertension, %</td>
<td>38.9</td>
<td>50.0</td>
<td>83.3</td>
</tr>
<tr>
<td>Primary reason for index PCI, %</td>
<td>5.6</td>
<td>25.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Acute MI</td>
<td>55.6</td>
<td>50.0</td>
<td>41.7</td>
</tr>
<tr>
<td>Unstable Angina</td>
<td>33.3</td>
<td>16.7</td>
<td>8.3</td>
</tr>
<tr>
<td>Stable Angina</td>
<td>5.6</td>
<td>8.3</td>
<td>0</td>
</tr>
<tr>
<td>Circumstances of index PCI, %</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Elective</td>
<td>75</td>
<td>66.7</td>
<td>41.7</td>
</tr>
<tr>
<td>Urgent</td>
<td>25</td>
<td>12.5</td>
<td>33.3</td>
</tr>
<tr>
<td>Emergent</td>
<td>0</td>
<td>20.8</td>
<td>25</td>
</tr>
<tr>
<td>Multivessel disease, %</td>
<td>55.6</td>
<td>83.3</td>
<td>75</td>
</tr>
<tr>
<td>Mean # significant lesions</td>
<td>2.7</td>
<td>3.5</td>
<td>2.9</td>
</tr>
<tr>
<td>Any total occlusion, %</td>
<td>33.3</td>
<td>41.7</td>
<td>50</td>
</tr>
<tr>
<td>Evidence of thrombus, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>16.7</td>
<td>33.3</td>
<td>50</td>
</tr>
<tr>
<td>Calcified lesions, %</td>
<td>5.6</td>
<td>33.3</td>
<td>58.3</td>
</tr>
<tr>
<td>Ostial lesions %</td>
<td>-</td>
<td>25</td>
<td>8.3</td>
</tr>
<tr>
<td>Ulcerated lesions, %</td>
<td>-</td>
<td>20.8</td>
<td>8.3</td>
</tr>
<tr>
<td>Bifurcation lesions, %</td>
<td>-</td>
<td>8.3</td>
<td>16.7</td>
</tr>
<tr>
<td>ACC/AHA Type C lesions, %</td>
<td>-</td>
<td>16.7</td>
<td>58.3</td>
</tr>
<tr>
<td># Vessels attempted, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>77.8</td>
<td>83.3</td>
<td>66.7</td>
</tr>
<tr>
<td>Single native</td>
<td>5.6</td>
<td>8.3</td>
<td>25</td>
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<tr>
<td>Double native</td>
<td>16.7</td>
<td>8.4</td>
<td>8.3</td>
</tr>
<tr>
<td>Graft +/- native vessels, %</td>
<td></td>
<td></td>
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</tr>
<tr>
<td># Lesions attempted, %</td>
<td>1</td>
<td>72.2</td>
<td>62.5</td>
</tr>
<tr>
<td>%</td>
<td>2</td>
<td>16.7</td>
<td>29.2</td>
</tr>
<tr>
<td>3</td>
<td>11.1</td>
<td>8.3</td>
<td>16.7</td>
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<tr>
<td>Medication use before or during index PCI, %</td>
<td>0</td>
<td>100</td>
<td>91.7</td>
</tr>
<tr>
<td></td>
<td>Heparin</td>
<td>GpIIb/IIIa receptor inhibitors</td>
<td>Clopidogrel or Ticlopidine</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------</td>
<td>--------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>29.2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>50</td>
<td>29.2</td>
</tr>
<tr>
<td></td>
<td>83.3</td>
<td>70.6</td>
<td>66.7</td>
</tr>
<tr>
<td></td>
<td>94.1</td>
<td>57.1</td>
<td>64.7</td>
</tr>
<tr>
<td></td>
<td>90.5</td>
<td>45.5</td>
<td>76.2</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>&lt;0.001</td>
<td>90.9</td>
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</tr>
</tbody>
</table>

SUPPLEMENTAL FIGURE

Hazard ratio (95% CI)  Hazard ratio (95% CI)

A) 30 days
CABG (N=251)

<table>
<thead>
<tr>
<th>Wave</th>
<th>Hazard Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave 1</td>
<td>0.22 (0.14-0.33)</td>
</tr>
<tr>
<td>Wave 2</td>
<td>0.21 (0.13-0.33)</td>
</tr>
<tr>
<td>Wave 3</td>
<td>0.10 (0.06-0.20)</td>
</tr>
<tr>
<td>Wave 4</td>
<td>0.20 (0.13-0.31)</td>
</tr>
<tr>
<td>Wave 5</td>
<td>0.07 (0.04-0.15)</td>
</tr>
</tbody>
</table>

Repeat PCI (N=113)

<table>
<thead>
<tr>
<th>Wave</th>
<th>Hazard Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave 1</td>
<td>2.38 (1.23-4.62)</td>
</tr>
<tr>
<td>Wave 2</td>
<td>1.34 (0.62-2.91)</td>
</tr>
<tr>
<td>Wave 3</td>
<td>1.92 (0.93-3.93)</td>
</tr>
<tr>
<td>Wave 4</td>
<td>1.77 (0.88-3.54)</td>
</tr>
<tr>
<td>Wave 5</td>
<td>1.89 (0.95-3.78)</td>
</tr>
</tbody>
</table>

B) 31-365 days
CABG (N=309)

<table>
<thead>
<tr>
<th>Wave</th>
<th>Hazard Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave 1</td>
<td>0.82 (0.61-1.11)</td>
</tr>
<tr>
<td>Wave 2</td>
<td>0.67 (0.48-0.93)</td>
</tr>
<tr>
<td>Wave 3</td>
<td>0.37 (0.24-0.58)</td>
</tr>
<tr>
<td>Wave 4</td>
<td>0.19 (0.11-0.32)</td>
</tr>
<tr>
<td>Wave 5</td>
<td>0.28 (0.18-0.45)</td>
</tr>
</tbody>
</table>

Repeat PCI (N=911)

<table>
<thead>
<tr>
<th>Wave</th>
<th>Hazard Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave 1</td>
<td>0.75 (0.62-0.90)</td>
</tr>
<tr>
<td>Wave 2</td>
<td>0.51 (0.41-0.64)</td>
</tr>
<tr>
<td>Wave 3</td>
<td>0.61 (0.49-0.76)</td>
</tr>
<tr>
<td>Wave 4</td>
<td>0.37 (0.29-0.48)</td>
</tr>
<tr>
<td>Wave 5</td>
<td>0.42 (0.32-0.53)</td>
</tr>
</tbody>
</table>

Lower risk in Dynamic registry  Higher risk in Dynamic registry
FIGURE LEGEND:

Adjusted Hazard ratios (95% confidence intervals) for effectiveness outcomes in the 1997-2006 Dynamic Registry waves (reference: 1985-86 PTCA Registry)