Change in Hospital-Level Use of Transradial Percutaneous Coronary Intervention and Periprocedural Outcomes

Insights from the National Cardiovascular Data Registry

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Background—Whether increasing use of radial access has improved percutaneous coronary intervention outcomes remains unknown. We sought to determine the relationship between increasing facility-level use of transradial percutaneous coronary intervention (TRI) and periprocedural outcomes.

Methods and Results—Within the National Cardiovascular Data Registry CathPCI Registry, we estimated the risk-adjusted association between hospital category of change in TRI use (during the 3-year period from 2009 to 2012) and trends in access site and overall bleeding, fluoroscopy time, and contrast use among 818 facilities with low baseline TRI use. There were 4 categories of hospital change in TRI use: very low (baseline, 0.2% increasing to 1.8% at the end of 3 years), low (0.9% increasing to 8.9%), moderate (1.6% increasing to 27.2%), and high (1.0% increasing to 45.1%). Risk-adjusted access site bleeding decreased over time for all hospital categories; however, the rate of decline varied across hospital categories (P for interaction, <0.001). The decrease in access site bleeding was significantly greater for hospitals with moderate or high increases in TRI use (relative risk, 0.45; 95% confidence interval, 0.36–0.56; P for comparison, 0.002). Similar findings were observed for overall bleeding. An increase in fluoroscopy time (≈1.3 minutes) was noted at hospitals with moderate and high use of TRI (P=0.01). Trends in contrast use were similar across hospital categories.

Conclusions—In a national sample of hospitals performing percutaneous coronary intervention, bleeding rates decreased over time for all hospital categories of change in TRI use. The decline in bleeding outcomes was larger at hospitals with increased adoption of TRI when compared with hospitals with minimal or no change in TRI use. (Circ Cardiovasc Qual Outcomes. 2014;7:00-00.)

Key Words: hemorrhage • hospitals • outcomes assessment • percutaneous coronary intervention

Bleeding is a common complication after percutaneous coronary intervention (PCI) and is associated with increased morbidity, mortality, and costs of care.1–5 In comparison with femoral access for PCI, several randomized trials have shown that radial access is associated with a reduced risk of periprocedural bleeding.6,7 Transradial access is also associated with shorter hospital stays, lower healthcare costs, and is a patient-preferred approach to PCI.8–10 In light of these potential benefits, the use of radial access for PCI is increasing.11–13 Whether increasing use of radial access has resulted in improved PCI outcomes in routine practice remains unknown.

During the transition to increased radial access use, it is possible that facility-level PCI outcomes could be compromised. For example, patients selected for transradial PCI (TRI) may be at lower risk of bleeding (eg, nonacute indications),12 thus minimizing the benefit of radial access while increasing the apparent bleeding rate among patients undergoing femoral PCI. In addition, the benefits of TRI may be small during early adoption because of a procedural learning curve.14 There are also concerns that greater use of TRI and the reduced risk of access site bleeding may lead to more liberal use of antithrombotic agents with a subsequent rise in nonaccess site bleeding.15 Moreover, as sites perform an increasing proportion of
WHAT IS KNOWN
• Bleeding is a common complication after percutaneous coronary intervention (PCI), is associated with poor outcomes, and is potentially modifiable through the use of radial access for the procedure.
• The use of radial access for PCI is increasing, but it remains unknown whether increasing use of radial access has resulted in improved PCI outcomes in routine practice.

WHAT THE STUDY ADDS
• In a national sample of 818 PCI hospitals with low baseline use of transradial PCI (TRI), 1 in 5 hospitals increased their use of TRI from <1% to >25% during a 3-year period of observation.
• Risk-adjusted access site and overall bleeding decreased over time for all hospitals, regardless of increase in TRI use.
• The temporal decline in bleeding outcomes was larger at hospitals with increased adoption of TRI relative to hospitals with little or no change in TRI use.

Methods
Data Source
The CathPCI Registry is the largest ongoing registry of PCI in the United States, with >1400 participating centers.29,30 Data captured in CathPCI includes detailed patient and hospital characteristics, including procedural indication, angiographic findings, interventions, and outcomes based on prespecified data elements defined by National Cardiovascular Data Registry. Data quality assurance is achieved through automatic system validation and reporting of data completeness, education and training for site data managers, and random on-site auditing.21

Study Population
We identified 1876758 PCI at 1382 hospitals that participated in CathPCI from July 2009 to June 2012. We excluded 6425 (0.3%) patients who died the same day as PCI and 869 (<0.1%) patients with missing data on the primary outcome of access site bleeding. We also excluded 462 (33.4%) facilities with missing quarters of participation in CathPCI or quarters of data that failed quality review during this time period and 13 (0.9%) facilities performing fewer than 50 PCIs annually to avoid inflation of variance because of small numbers. Because our primary interest was the change in facility-level PCI outcomes during the transition from low baseline rates of radial use to increased rates of use, we excluded 89 (6.5%) facilities with ≥10% radial use at baseline (ie, in year 1 of the study period). Our final analytic cohort included 818 hospitals that performed 1438816 PCI.

Change in Facility-Level Use of TRI
Our exposure of interest was the facility-level change in TRI use during the 3-year study period. To identify categories of hospital-level change in TRI use, we performed latent growth curve analysis with time modeled continuously across quarters. Latent class growth curve analysis is used to identify distinct subgroups of change across time. Each hospital is considered to have its own observed trajectory of TRI use that can be described using an estimated model. Hospitals can then be sorted into groups based on their estimated changes over time. Hospitals within each subgroup have similar changes across time and are, therefore, considered to be a latent class. Multiple models can be fit with differing numbers of latent classes, and each of these models can then be compared using the Bayesian Information Criteria and posterior probabilities of belonging to a latent class. The best model differentiates well between the identified groups and makes clinically meaningful sense while still fitting the data well based on Bayesian Information Criteria. We explored models with 3, 4, and 5 latent classes of change in TRI use.2 We found the model with 4 categories fit the data well, provided adequate differentiation of hospital trends in TRI use and maintained reasonable sample sizes at the facility level. All outcomes are reported using this differentiation (see Data Supplement for comparison of model output).

Outcome Variables
The primary outcome was access site bleeding. Access site bleeding is defined by CathPCI data as external bleeding associated with a hemoglobin drop of ≥3 g/dL, transfusion of whole blood or packed red blood cells, or procedural intervention/surgery at the bleeding site to reverse/stop or correct the bleeding, an acute fall in hemoglobin >3 g/dL without other obvious source (eg, gastrointestinal, genitourinary, operative, or hemolysis) that is attributable to intraprocedural blood loss (eg, during equipment exchanges), or a hematoma with a diameter >10 cm for femoral PCIs, >5 cm for brachial PCIs, or >3 cm for TRIs. Our secondary outcomes included overall periprocedural bleeding, fluoroscopy time in minutes, contrast use in milliliters. Overall periprocedural bleeding is defined in CathPCI as a bleeding event occurring within 72 hours of the procedure that is associated with any of the following: hemoglobin drop of ≥3 g/dL, transfusion of whole blood or packed red blood cells, or procedural intervention/surgery at the bleeding site to reverse/stop or correct the bleeding. In the analysis of fluoroscopy time, we excluded 16753 (1.2%) patients without a fluoroscopy time reported. In the analysis of contrast use, we excluded 18450 (1.3%) patients with missing or extreme values (the highest and lowest 0.5% of reported contrast use) to avoid the inclusion of potentially erroneous outcome data in our analyses. Finally, we evaluated in-hospital mortality rates in exploratory analyses.

Statistical Analysis
We compared patient characteristics (demographics, risk factors and comorbid conditions, symptoms, clinical presentation, and predicted bleeding risk from CathPCI models)23 and hospital-level characteristics (location, type, teaching status, and annual PCI volume) across categories of hospital change in TRI use identified from latent growth curve analysis as described above. Comparisons of patient characteristics were completed using ANOVA for continuous variables and χ² test for categorical variables. Hospital characteristics were compared using Kruskal–Wallis test for non-normally distributed continuous variables (eg, annual PCI volume and hospital bed size) and χ² test for categorical variables.
Results

Hospital Change in TRI Use

Categories of hospital change in TRI use identified from latent class growth analysis are shown in Figure 1. We observed 327 (40.0%) hospitals with a very low increase in TRI use, with a baseline median TRI rate of 0.2% and a TRI rate of 1.8% in the last quarter of study. A low increase in TRI use was observed at 314 (38.4%) hospitals, with a baseline median TRI rate of 0.9% increasing to a median of 8.9%. A moderate increase in TRI use was observed at 136 (16.6%) hospitals, with an increase from 1.6% at baseline to 27.2%. A high rate of increase in TRI use was seen at only 41 (5.0%) hospitals, with a change in TRI rates from 1.0% at baseline to 45.1% by the end of the observation period.

Patient and Hospital Characteristics

The comparison of patient characteristics by hospital category of change in TRI use was statistically significant for all characteristics given our large sample size, but these differences were clinically modest (Table 1). As determined from CathPCI bleeding risk models, patients’ predicted bleeding risk was similar across hospital categories of change in TRI use at baseline (predicted bleeding among all patients undergoing PCI from lowest to highest hospital category of TRI increase, 5.7% versus 5.5% versus 5.7% versus 5.5%) and at the end of 3 years (6.3% versus 6.0% versus 6.4% versus 5.9%). Baseline predicted bleeding risk across hospital categories was also similar among patients undergoing TRI (4.2% versus 4.0% versus 4.3% versus 4.4%) and femoral PCI (5.7% versus 5.5% versus 5.7% versus 5.6%). At the end of 3 years, predicted bleeding risk among patients undergoing TRI was similar across hospital categories (4.2% versus 4.1% versus 4.4% versus 4.3%), whereas predicted bleeding risk among patients undergoing femoral PCI seemed slightly higher at hospitals with higher use of TRI (6.3% versus 6.2% versus 7.0% versus 7.4%). Baseline use of bivalirudin was similar across hospital categories (48% versus 55% versus 52% versus 52%) while use at the end of 3 years was lower in hospitals with a larger increase in TRI use (62% versus 67% versus 63% versus 54%). The use of glycoprotein IIb/IIIa inhibitors decreased during the study period, and rates of use were similar across hospitals at baseline (28% versus 25% versus 29% versus 22%) and at
Table 1. Patient and Hospital Characteristics by Hospital Category of Change in TRI Use

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Total</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospitals</td>
<td>881</td>
<td>327</td>
<td>314</td>
<td>136</td>
<td>41</td>
<td>…</td>
</tr>
<tr>
<td>Hospital median radial PCI use, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0.7</td>
<td>0.2</td>
<td>0.9</td>
<td>1.6</td>
<td>1.0</td>
<td>…</td>
</tr>
<tr>
<td>End of observation (last quarter of year 3)</td>
<td>5.5</td>
<td>1.8</td>
<td>8.9</td>
<td>27.2</td>
<td>45.1</td>
<td>…</td>
</tr>
<tr>
<td>Patients</td>
<td>1,438,516</td>
<td>432,080</td>
<td>670,191</td>
<td>254,230</td>
<td>82,015</td>
<td>…</td>
</tr>
</tbody>
</table>

Demographics

<table>
<thead>
<tr>
<th>Age; mean (SD), y</th>
<th>65 (12)</th>
<th>65 (12)</th>
<th>65 (12)</th>
<th>64 (12)</th>
<th>64 (12)</th>
<th>&lt;0.001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>467,713</td>
<td>516,516</td>
<td>432,080</td>
<td>136,080</td>
<td>41,516</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>White</td>
<td>1,269,434</td>
<td>383,963</td>
<td>587,550</td>
<td>222,292</td>
<td>75,629</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Clinical risk factors and comorbidities

<table>
<thead>
<tr>
<th>Diabetes mellitus</th>
<th>522,585</th>
<th>156,039</th>
<th>246,813</th>
<th>90,705</th>
<th>29,028</th>
<th>&lt;0.001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertension</td>
<td>1,177,567</td>
<td>351,534</td>
<td>551,806</td>
<td>207,102</td>
<td>67,125</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Dyslipidemia</td>
<td>1,146,597</td>
<td>341,438</td>
<td>535,256</td>
<td>204,983</td>
<td>64,920</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Tobacco use (within 1 y)</td>
<td>395,975</td>
<td>121,611</td>
<td>182,621</td>
<td>68,690</td>
<td>23,053</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Previous PCI</td>
<td>583,524</td>
<td>173,264</td>
<td>276,981</td>
<td>99,979</td>
<td>33,300</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Previous CABG</td>
<td>269,578</td>
<td>80,128</td>
<td>128,388</td>
<td>44,737</td>
<td>16,325</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Previous MI</td>
<td>430,996</td>
<td>126,380</td>
<td>201,333</td>
<td>77,134</td>
<td>26,149</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Heart failure</td>
<td>168,788</td>
<td>48,944</td>
<td>79,579</td>
<td>29,805</td>
<td>10,460</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
<td>176,410</td>
<td>52,027</td>
<td>83,718</td>
<td>30,613</td>
<td>10,052</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Peripheral arterial disease</td>
<td>180,172</td>
<td>51,299</td>
<td>86,393</td>
<td>30,990</td>
<td>11,490</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Chronic lung disease</td>
<td>218,567</td>
<td>68,335</td>
<td>101,040</td>
<td>35,288</td>
<td>13,404</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Dialysis</td>
<td>34,180 (2%)</td>
<td>10,232 (2%)</td>
<td>16,420 (2%)</td>
<td>5,992 (2%)</td>
<td>1,536 (2%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BMI; mean (SD)</td>
<td>30 (6)</td>
<td>30 (6)</td>
<td>30 (6)</td>
<td>30 (6)</td>
<td>30 (6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>NYHA III–IV</td>
<td>52,980 (60%)</td>
<td>23,192 (59%)</td>
<td>33,436 (60%)</td>
<td>16,412 (61%)</td>
<td>49,50 (60%)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

CAD presentation

| STEMI | 227,635 (16%) | 71,205 (16%) | 100,099 (15%) | 39,100 (15%) | 12,511 (15%) | …       |
| Non-STEMI | 267,858 (19%) | 79,179 (18%) | 120,554 (18%) | 52,307 (21%) | 15,818 (19%) | <0.001 |
| Unstable angina | 542,983 (38%) | 159,045 (37%) | 264,557 (39%) | 92,531 (36%) | 26,850 (33%) | …       |
| Non-ACS | 399,794 (28%) | 122,559 (28%) | 184,958 (28%) | 65,448 (26%) | 26,829 (33%) | …       |

Bleeding risk, %

<table>
<thead>
<tr>
<th>Baseline: quarter 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>All PCI</td>
</tr>
<tr>
<td>Radial PCI</td>
</tr>
<tr>
<td>Femoral PCI</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>End of observation: quarter 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>All PCI</td>
</tr>
<tr>
<td>Radial PCI</td>
</tr>
<tr>
<td>Femoral PCI</td>
</tr>
</tbody>
</table>

Antithrombotic use

<table>
<thead>
<tr>
<th>Baseline: quarter 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heparin only</td>
</tr>
<tr>
<td>Bivalirudin</td>
</tr>
<tr>
<td>Glycoprotein Inhibitor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>End of observation: quarter 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heparin only</td>
</tr>
<tr>
<td>Bivalirudin</td>
</tr>
<tr>
<td>Glycoprotein Inhibitor</td>
</tr>
</tbody>
</table>

(Continued)
the end of observation (19% versus 15% versus 16% versus 19%). Hospitals with a higher rate of change in TRI use were more likely to be teaching hospitals (from lowest to highest category of TRI increase, 34% versus 48% versus 51% versus 56%) and less likely to be in the Western United States (21% versus 23% versus 21% versus 7%). Otherwise, differences in characteristics of hospitals by category of TRI use were small (Table 1). Exploratory analyses of observed mortality rates at baseline and at end of observation were also similar across hospitals (Data Supplement).

Bleeding Outcomes

Observed rates of access site bleeding decreased over time across all categories of TRI change (Figure 2A; Data Supplement). The risk-adjusted trend in access site bleeding (as determined by RR of bleeding in the last quarter of observation when compared with the first quarter) decreased for all hospital categories, and trends in access site bleeding were different across hospital categories (P for interaction, <0.001; Table 2). When compared with hospitals with very low or low increase in the use of TRI, the decline in risk-adjusted overall bleeding over time was greater at hospitals with moderate or high increase in the use of TRI (RR, 0.51; 95% CI, 0.43–0.61 versus RR, 0.69; 95% CI, 0.63–0.74; P for comparison, 0.002). Similar results were observed in secondary analyses that adjusted for antithrombotic strategy and the use of vascular closure devices in addition to bleeding risk (Table 2). Trends in risk-adjusted access site and overall bleeding by hospital category of change in TRI use are also shown in Figure 3A and 3B.

Fluoroscopy Time

Observed fluoroscopy times did not change at facilities with very low change in TRI use, whereas fluoroscopy times at facilities with increasing use of TRI increased by ≈1 minute (Figure 2C; Data Supplement). In the risk-adjusted model, trends in fluoroscopy time were different across hospital categories (P for interaction, 0.01) with an increasing trend in fluoroscopy time at hospitals with moderate or high change in the use of TRI (Table 3). When compared with hospitals with very low or low increase in the use of TRI, fluoroscopy times increased over time at hospitals with moderate or high increases in the use of TRI (1.3 minutes: 95% CI, 0.5–2.2 minutes versus 0.2 minutes: 95% CI, 0.1–to 0.4 minutes; P for comparison, 0.01). Trends in risk-adjusted fluoroscopy time by hospital category of change in TRI use are also shown in Figure 3C.

Contrast Use

Observed contrast use decreased over time for all hospital categories of change in TRI use (Figure 2D; Data Supplement). The decreasing trends in risk-adjusted contrast volume were
similar across categories of TRI use ($P$ for interaction, 0.86; Table 3). Trends in risk-adjusted contrast use by hospital category of change in TRI use are shown in Figure 3D.

**Discussion**

We sought to determine the relationship between increasing hospital use of TRI and trends in periprocedural outcomes.

**Table 2. Relative Risk of Bleeding by Hospital Category of Change in TRI Use**

<table>
<thead>
<tr>
<th>Quarter of Observation (3-Mo Interval)</th>
<th>Hospital Categories of Change in TRI Use</th>
<th>$P$ for Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Very Low</td>
<td>Low</td>
</tr>
<tr>
<td>Access site bleeding outcomes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bleeding risk adjusted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>12</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>Bleeding risk, antithrombotic, and vascular closure device use adjusted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>12</td>
<td>Reference</td>
<td>Reference</td>
</tr>
</tbody>
</table>

TRI indicates transradial percutaneous coronary intervention.
during a 3-year period. In a national sample of 818 hospitals with low baseline use of TRI, ≈40% of hospitals continued to use TRI in fewer than 2% of patients, whereas another 40% of hospitals increased use of TRI to ≈9% by the end of 3 years. Just ≥15% of hospitals had a moderate increase in TRI use to slightly ≥25% and only 5% achieved high rates of TRI use that approached 50%. Although rates of access site bleeding decreased over time across all categories of hospital change in TRI use, the risk-adjusted decrease in access site bleeding was 55% ≥3 years at hospitals with moderate to high increases in TRI use when compared with 35% at hospitals with very low to low TRI use. Analysis of overall bleeding rates demonstrated similar findings. Hospitals with increasing TRI use were associated with an increasing trend in fluoroscopy time relative to hospitals with little to no change in TRI use, and trends in contrast use were similar across all hospital categories. Our findings suggest that facilities transitioning to greater use of TRI are achieving larger reductions in periprocedural

Table 3. Relative Change in Fluoroscopy Time and Difference in Contrast Volume by Hospital Category of Change in TRI Use

<table>
<thead>
<tr>
<th>Quarter of Observation (3-Mo Interval)</th>
<th>Hospital Categories of Change in TRI Use</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>P for Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative change in fluoroscopy time, min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>–0.1 (–0.5 to 0.3)</td>
<td>0.4 (–0.01 to 0.9)</td>
<td>1.0 (0.4 to 1.7)</td>
<td>1.6 (0.1 to 3.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference in contrast volume, mL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bleeding risk adjusted</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>1</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>–6.2 (–9.9 to –2.5)</td>
<td>–5.4 (–9.2 to –1.7)</td>
<td>–8.2 (–13.5 to –2.9)</td>
<td>–7.6 (–18.2 to 3.0)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TRI indicates transradial percutaneous coronary intervention.
bleeding than facilities that continue to use a predominantly femoral approach for PCI.

Although the potential benefits of TRI have not been demonstrated in all studies, TRI has been shown to improve patient outcomes in several randomized controlled trials. However, the benefits of therapies demonstrated in highly controlled clinical trials can be lost when applied to routine clinical practice. This may be particularly true for TRI given evidence of a learning curve that may result in diminished benefit during early adoption. Although several observational studies have subsequently added to the weight of trial evidence suggesting the benefits of TRI, observational studies of TRI at the patient-level are subject to selection bias. For example, as operators adopt TRI they may feel more comfortable proceeding with radial access in patients at lower bleeding risk (eg, nonacute indications). Finally, increased use of radial access may have unintended consequences on the management and complication rates of patients undergoing femoral PCI. As a result, it has remained unclear if increasing use of TRI in routine practice has resulted in better overall PCI outcomes.

In the present study, we evaluated temporal trends in hospital-level outcomes in relation to changing hospital-level patterns in the use of TRI. This approach has major strengths in ascertaining the effect of TRI adoption on overall practice outcomes. First, all patient outcomes are attributed to a facility, regardless of whether the patient underwent PCI via radial or femoral access. As a result, if facilities select patients with lower bleeding risk for TRI, the effect on facility-level outcomes is balanced by the higher risk among the remaining patients undergoing femoral PCI. Second, our approach allows for the comparison of trends in bleeding outcomes among facilities with increasing use of TRI relative to baseline secular trends. A previous study found a decreasing temporal trend in bleeding complications after PCI that was largely attributable to changes in antithrombotic strategies. The present study suggests that bleeding complication rates have continued to decline in recent years and may reflect the continued changes in antithrombotic strategies, with greater use of bivalirudin and less use of glycoprotein IIb/IIIa inhibitors. However, the decline in bleeding outcomes was more marked at hospitals with increased adoption of TRI when compared with those with minimal or no change in TRI use, even after accounting for antithrombotic strategies and the use of vascular closure devices.

Previous studies have shown that the use of TRI is associated with longer fluoroscopy time. Consistent with these previous studies, we observed an increase in fluoroscopy times at hospitals with increasing use of TRI. The relative change in fluoroscopy times at hospitals with increasing TRI use was modest (≈1 minute) but likely reflects increased use of fluoroscopy to guide operators through upper extremity vessels or during coronary artery cannulation. As much of the radiation exposure in the setting of TRI occurs from cine-angiography, it is unclear whether this increase in fluoroscopy time reflects significant differences in radiation dose and subsequent risk of adverse patient outcomes. In comparison, the volume of contrast used during PCI has been directly correlated with patient outcomes, such as acute kidney injury. We observed no differences in contrast use trends across hospital categories of change in TRI use.

The present study should be considered in the context of potential limitations. First, our study is an observational design and we cannot exclude unmeasured confounding, despite our application of risk-adjustment using covariates from contemporary models. Importantly, strategies other than radial access may contribute to declines in PCI bleeding rates as suggested by previous analyses of temporal bleeding trends in relation to changes in antithrombotic strategies. However, our secondary analyses that adjusted for antithrombotic strategies and the use of vascular closure devices continued to demonstrate a greater decline in bleeding outcomes at hospitals with greater use of TRI. Second, our analysis did not evaluate facilities with established high rates of radial use. As we sought to determine the effect of facilities changing to radial access on PCI outcomes during the period of transition, we excluded facilities with established high rates of TRI use. Additional study may inform whether persistently high radial use results in additional improvements in patient outcomes. Third, our analysis does not account for the potential effect of transferred patients where there may be greater use of femoral access and risk of bleeding. Fourth, our analysis excluded facilities with low annual PCI volumes to minimize instability in estimates related to inadequate sample size. As a result, our findings may not be generalizable to hospitals with low PCI volumes. Fifth, we are unable to comment on the effect of increasing TRI use on procedural success by access site because of lack of data on access site crossover. We also lack data on rates of readmission and long-term mortality. Finally, our study does not account for potentially important structural aspects of hospitals transitioning to TRI that may contribute to declines in bleeding rates (eg, organizational values and goals, senior management involvement, and broad staff presence). Evaluation of these structural aspects in relation to uptake of TRI and resultant improvements in outcomes is an area for future research.

In conclusion, in this large national sample of PCI hospitals, we found that the facility-level temporal decline in bleeding outcomes was greatest at hospitals with moderate to high increases in TRI use. Temporal trends in contrast use were similar across hospital categories of change in TRI use, whereas fluoroscopy time was modestly higher at facilities with increasing use of TRI. Our findings suggest that facilities changing to greater use of TRI are associated with larger reductions in periprocedural bleeding than facilities that have not adopted a radial approach.

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in the CathPCI registry, and representatives of the CathPCI Research and Publications committee approved the final article.

Disclosures

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## Table A. Observed In-Hospital Mortality by Hospital Categories of Change in TRI Use

<table>
<thead>
<tr>
<th>In-hospital Mortality (%)</th>
<th>Hospital Categories of Change in TRI Use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Very Low</td>
</tr>
<tr>
<td>Baseline – Quarter 1</td>
<td>1.0 (0.9-1.1)</td>
</tr>
<tr>
<td>End of Observation – Quarter 12</td>
<td>1.1 (1.0-1.2)</td>
</tr>
</tbody>
</table>
Figure A. Latent growth curve analysis of hospital change in TPI use over time.

A1. Model with 3 categories of hospital change in TPI use

A2. Model with 4 categories of hospital change in TPI use
A3. Model with 5 categories of hospital change in TPI use
Figure B. Observed Outcome Trends (with confidence intervals) by Hospital Category of Change in TRI Use

B1. In-Hospital Mortality (%)

B2. Access Site Bleeding Rate
B3. Overall Bleeding Rate

B4. Contrast Volume
B5. Fluoroscopy Time