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Costs of Transradial Percutaneous Coronary Intervention

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Objectives This study sought to evaluate the costs of transradial percutaneous coronary intervention (TRI) and transfemoral percutaneous coronary intervention (TFI) from a contemporary hospital perspective.

Background Whereas the TRI approach to percutaneous coronary intervention (PCI) has been shown to reduce access-site complications compared with TFI, whether it is associated with lower costs is unknown.

Methods TRI and TFI patients were identified at 5 U.S. centers. The primary outcome was the cost of percutaneous coronary intervention (PCI) hospitalization, defined as cost on the day of PCI through hospital discharge. Cost was obtained from each hospital's cost accounting system. Independent costs of TRI were identified using propensity-scoring methods with inverse probability weighting. Secondary outcomes of interest were bleeding, in-hospital mortality, and length of stay, which were stratified by pre-procedural risk and PCI indication.

Results In 7,121 PCI procedures performed from January 1, 2010, to March 31, 2011, TRI was performed in 1,219 (17%) patients and was associated with shorter lengths of stay (2.5 vs. 3.0 days; $p < 0.001$) and lower bleeding events (1.1% vs. 2.4%, adjusted odds ratio [OR]: 0.52, 95% confidence interval [CI]: 0.34 to 0.79; $p = 0.002$). TRI was associated with a total cost savings of $830 (95% CI: $296 to $1,364; $p < 0.001$), of which $130 (95% CI: –$99 to $361; $p = 0.112$) were procedural savings and $705 (95% CI: $212 to $1,238; $p < 0.001$) were post-procedural savings. There was an associated graded increase in savings among patients at higher predicted risk of bleeding: low risk: $642 (95% CI: $43 to $1,236; $p = 0.035$); moderate risk: $706 (95% CI: $104 to $1,308; $p = 0.029$); and high risk: $1,621 (95% CI: $271 to $2,971, $p = 0.039$).

Conclusions TRI was associated with a cost savings exceeding $800 per patient relative to TFI. Increased adoption of TRI may result in cost savings at hospitals. (J Am Coll Cardiol Intv 2013;6:827–34) © 2013 by the American College of Cardiology Foundation

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The frequency of transradial percutaneous coronary intervention (TRI) is increasing in the United States (1). TRI is associated with reduced access site bleeding complications compared with transfemoral percutaneous coronary intervention (TFI) (1–8). Moreover, TRI is associated with earlier ambulation, reduced length of stay (LOS) and patient satisfaction (4). Yet, proficiency in TRI requires overcoming a defined learning curve (9,10), which is associated with higher percutaneous coronary intervention (PCI) failure rates initially (5), resulting in increased access-site crossover (3,11), which is associated with increased resource utilization (3,11,12).

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Although the clinical benefit of TRI has been studied, a contemporary and detailed cost analysis between TRI and TFI from the hospitals' perspective are lacking (12,13). To better understand the contemporary economic impact of TRI, we compared the costs and clinical outcomes between TRI and TFI at 5 U.S. hospitals.

Abbreviations and Acronyms

CI = confidence interval(s)
IPW = inverse probability weighting
LOS = length of stay
OR = odds ratio(s)
PCI = percutaneous coronary intervention
STEMI = ST-segment elevation myocardial infarction
TFI = transfemoral percutaneous coronary intervention
TRI = transradial percutaneous coronary intervention

Methods

The study population consisted of a retrospective cohort of patients undergoing PCI from January 1, 2010, to March 31, 2011, at 5 U.S. hospitals (Saint Luke's Mid America Heart Institute, Kansas City, Missouri; Spectrum Health, Grand Rapids, Michigan; Wake Forest Baptist Medical Center, Winston-Salem, North Carolina; Presbyterian Healthcare, Charlotte, North Carolina; Aurora Baycare Medical Center, Green Bay, Wisconsin). Patients who underwent PCI at each hospital were included. Patients who underwent >1 PCI during admission were excluded because it is difficult in such cases to attribute an in-hospital bleeding event to a single procedure. Patients with cardiogenic shock and chronic total occlusion were also excluded. When >1 access site was used, the primary location of percutaneous entry for a given procedure is the access site used to perform the majority of the procedure. The frequency of crossover was not collected.

In accordance with a data use agreement, a deidentified limited dataset was obtained from each center with all elements conforming to NCDR (National Cardiovascular Data Registry) CathPCI Registry (version 4.0) data definitions (14). PCI procedure cost data were obtained directly from each hospital's cost accounting system and linked to the limited dataset by a unique, randomly generated patient identifier. Neither the clinical nor the cost dataset contained patient identifiable information. The analysis was then performed on this combined dataset. Each respective hospital's institutional review board approved this study.

Hospital PCI costs. The primary outcome of interest was the cost of PCI hospitalization, which was defined as the cost on the day of PCI through hospital discharge, from the hospital's perspective. Patient-level PCI costs were obtained from the accounting system at each hospital and consisted of equipment, resources, personnel, and other direct and indirect costs. Because direct and indirect costs were obtained from each hospital and were not uniformly defined, they were combined and included in total costs but not individually analyzed. Because cost data are patient-level, costs for bleeding and LOS were estimated through regression cost modeling. Costs prior to the PCI procedure were not included. Total costs were categorized as procedural costs (incurred on the day of the procedure) and post-procedural costs (incurred on the day after the procedure through discharge). To normalize costs across hospitals to the national average, the Dartmouth Atlas of Health Care 2009 county level price-, age-, sex-, and race-adjusted data were applied (15). To remove extreme outliers, individual hospital costs were trimmed to the 99th percentile.

Clinical outcomes. Secondary outcomes of interest were post-PCI bleeding within 72 h, LOS, and in-hospital mortality from all causes. Post-PCI bleeding was defined in accordance with CathPCI (version 4.0) as a suspected bleeding with transfusion, a drop in hemoglobin of >3.0 g/dl, or a procedural intervention to correct the bleeding event.

Statistical analysis. Demographic data are described as mean ± SD for continuous variables and number (percentage) for categorical variables and compared using Student *t* tests and

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chi-square tests, respectively. To obtain independent costs for each access type and mitigate selection bias and confounding, a propensity score model was developed using logistic regression to predict use of TRI from the following variables: age; sex; race; insurance type; estimated glomerular filtration rate; ST-segment elevation myocardial infarction (STEMI); non-STEMI; acute coronary syndromes; PCI indication (elective, STEMI and non-STEMI); hypertension; prior PCI; peripheral vascular disease; prior heart failure; glycoprotein IIb/IIIa inhibitor use; bivalirudin use; low molecular weight heparin use; unfractionated heparin use; Canadian Cardiovascular Society angina class; New York Heart Association class; and number of stents used (as a proxy for disease severity). A hierarchical generalized linear mixed model was developed using inverse probability weighting (IPW) (16) with total hospital cost as the dependent variable and access location (TRI or TFI) as the independent variable. Individual weights were stabilized to account for the effect of extreme weights in the model (16). Along with the IPW, additional covariates included: type of anticoagulant; number of drug-eluting stents used; closure device used; and PCI indication. To account for variation in PCI costs across hospitals, a hierarchical modeling structure with hospital site as a random effect was used. To ascertain adequacy of the model with IPW, standardized differences in covariate imbalances with and without the IPW are displayed in Online Figure 1 (17–19). Costs were trimmed back to the 99th percentile to remove extreme outliers. Then bootstrapping using 1,000 replicates with replacement was applied to the model to account for skewness in the data (20,21). Median, 2.5%, and 97.5% estimates were used to determine the average costs and 95% confidence intervals, respectively. Patients were further stratified into low, moderate, and high bleeding risk categories according to the NCDR CathPCI bleeding risk model (22,23), with total, procedural, and post-procedural costs analyzed for each subgroup. To determine post-procedural TRI costs attributable to bleeding events and LOS, a "nested" modeling approach was used, where bleeding and LOS variables were added 1-by-1 as independent covariates to the existing cost model and then compared to the original cost model. In the first model, in-hospital bleeding was added, and the change in TRI post-procedural savings was deemed attributed to in-hospital bleeding. The second model included in-hospital bleeding and LOS, with the change attributed to LOS.

SECONDARY OUTCOMES. Other outcomes of interest included: LOS; post PCI bleeding within 72 h; and in-hospital mortality. Differences were estimated using IPW hierarchical generalized linear multivariable regression modeling (for LOS) and IPW hierarchical multivariable logistic regression modeling (for bleeding and mortality). Analyses were repeated for each bleeding risk. We also tested an interaction term between TRI and bleeding risk in the LOS model. Statistical significance was defined as $p < 0.05$. All analyses were performed at Saint Luke's Mid America Heart Institute using SAS (version 9.3, SAS Institute, Cary, North Carolina).

Results

Demographic and descriptive statistics. The 5 sites performed 7,121 (range: 418 to 2,862) eligible PCI procedures from January 1, 2010, to March 31, 2011. TRI was performed in 1,219 (17%) (range: 129 to 467; 11% to 38%) of all PCI procedures. Clinical and demographic characteristics are shown in Table 1. TRI patients were younger and less likely to undergo primary PCI for STEMI; had fewer risk factors and comorbidities such as hypertension, peripheral vascular disease, and prior heart failure; and had higher GFR and lower probabilities of bleeding. Unfractionated heparin (with or without glycoprotein IIb/IIa) was more frequently used in TRI, whereas bivalirudin was used less often (Table 1).

Bleeding and mortality outcomes. In-hospital bleeding occurred in 1.1% of TRI and 2.4% of TFI procedures ($p = 0.006$). After IPW adjustment, the difference was statistically significant (odds ratio [OR]: 0.52, 95% confidence interval [CI]: 0.34 to 0.79; $p = 0.002$). Unadjusted in-hospital mortality occurred in 0.3% and 0.8%, respectively ($p = 0.095$).

Length of stay. LOS was 2.5 days in the TRI group (95% CI: 2.09 to 2.89) compared with 3.0 days (95% CI: 2.60 to 3.35) in the TFI group, a difference of 0.5 days favoring TRI (95% CI: 0.25 to 0.72; $p < 0.001$). The interaction term between access location (radial or femoral) and bleeding risk was significant for the outcome of LOS ($p = 0.048$). LOS was 0.31 days shorter (95% CI: 0.12 to 0.50; $p = 0.0015$) in the low bleeding risk group, 0.16 days shorter (95% CI: −0.20 to 0.52; $p = 0.38$) in the moderate bleeding risk group, and 0.98 days shorter (95% CI: 0.18 to 1.79; $p = 0.017$) in the high bleeding risk group. After adjustment, the differences narrowed but remained statistically significant (Table 2). The rate of same-day discharge was 4.4% and 2.8% in the TRI and TFI groups, respectively ($p = 0.001$).

Hospital costs. Total unadjusted costs were $1,541 (95% CI: $1,052 to $2,031; $p < 0.001$) lower in the TRI than the TFI group. After risk adjustment, the difference decreased to $830 (95% CI: $296 to $1,364; $p < 0.001$). Procedural cost savings of $130 (95% CI: −$99 to $361; $p = 0.112$) with TRI were not significant, whereas post-procedural savings of $705 (95% CI: $212 to $1,238; $p < 0.001$) were significant. In stepwise regression with nested models, 12% of the total cost savings ($99) was attributable to decreased bleeding, and 50% of the cost savings ($414) in TRI was due to the 0.38-day-shorter LOS.

Unadjusted and adjusted cost savings by bleeding risk category are shown in Table 3. Greater savings were observed as bleeding risk increased.

Table 1. Demographic and Clinical Characteristics

	Total (n = 7,121)	Radial (n = 1,219)	Femoral (n = 5,902)	p Value
Age, yrs	64.7 ± 12.1	62.8 ± 11.5	65.1 ± 12.2	<0.001
Male	4,959 (69.6)	862 (70.8)	4,097 (69.4)	0.349
Race				0.306
Caucasian	6,487 (91.1)	1,122 (92.0)	5,365 (90.9)	
African American	413 (5.8)	59 (4.8)	354 (6.0)	
Asian	46 (0.6)	9 (0.7)	37 (0.6)	
Native American	11 (0.2)	0	11 (0.2)	
Other	164 (2.3)	29 (2.4)	135 (2.3)	
Admission diagnosis				<0.001
No angina	665 (9.3)	89 (7.3)	576 (9.8)	
Symptoms unlikely	331 (4.7)	72 (5.9)	259 (4.4)	
Stable angina	816 (11.5)	119 (9.8)	697 (11.8)	
Unstable angina	3,007 (42.3)	513 (42.1)	2,494 (42.3)	
Non-STEMI	1,329 (18.7)	331 (27.2)	998 (16.9)	
STEMI	966 (13.6)	95 (7.8)	871 (14.8)	
Indication for PCI				<0.001
Elective	2,894 (40.7)	487 (40.0)	2,407 (40.8)	
Urgent	2,503 (35.2)	507 (41.6)	1,996 (33.9)	
Emergency	1,043 (14.7)	89 (7.3)	954 (16.2)	
Salvage	674 (9.5)	136 (11.2)	538 (9.1)	
Insurance type				<0.001
Medicare/Medicaid	4,324 (60.7)	695 (57.0)	3,629 (61.5)	
Private	2,307 (32.4)	432 (35.4)	1,875 (31.8)	
Other	80 (1.1)	27 (2.2)	53 (0.9)	
None	410 (5.8)	65 (5.3)	345 (5.8)	
Hypertension	5,917 (83.1)	980 (80.4)	4,937 (83.7)	0.006
CCS class				<0.001
No angina	1,775 (25.0)	321 (26.3)	1,454 (24.7)	
Class 1	207 (2.9)	41 (3.4)	166 (2.8)	
Class 2	603 (8.5)	60 (4.9)	543 (9.2)	
Class 3	2,633 (37.0)	391 (32.1)	2,242 (38.0)	
Class 4	1,896 (26.7)	406 (33.3)	1,490 (25.3)	
NYHA class				0.047
None	6,384 (89.7)	1,110 (91.1)	5,274 (89.4)	
Class I	114 (1.6)	25 (2.1)	89 (1.5)	
Class II	115 (1.6)	11 (0.9)	104 (1.8)	
Class III	212 (3.0)	32 (2.6)	180 (3.0)	
Class IV	296 (4.2)	41 (3.4)	255 (4.3)	
Previous PCI	2,971 (41.7)	498 (40.9)	2,473 (41.9)	0.499
Peripheral vascular disease history	1,128 (15.8)	145 (11.9)	983 (16.7)	<0.001
Prior congestive heart failure	1,063 (14.9)	147 (12.1)	916 (15.5)	0.002
Estimated glomerular filtration rate, ml/min/1.73 m^2	76.2 ± 26.9	81.5 ± 26.5	75.1 ± 26.9	<0.001
Missing	321	20	301	
Imputed glomerular filtration rate, ml/min/1.73 m^2	76.1 ± 26.3	81.4 ± 26.3	75.0 ± 26.2	<0.001
Admission status, in-patient	5,538 (77.8)	1,025 (84.1)	4,513 (76.5)	<0.001
Same-day discharge	212 (3.0)	54 (4.4)	158 (2.7)	0.001

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Discussion

This study provides a contemporary description of the costs associated with TRI compared with TFI in patients undergoing PCI. A novel finding is that TRI is associated with cost savings of approximately $800 per PCI procedure. The extent of cost savings increased substantially among patients at higher bleeding risk. Finally, the cost savings

Table 1. Continued

	Total (n = 7,121)	Radial (n = 1,219)	Femoral (n = 5,902)	p Value
Anticoagulation and devices				
Glycoprotein IIb/IIIa	1,744 (24.6)	406 (33.3)	1,338 (22.7)	<0.001
Bivalirudin	3,520 (49.5)	515 (42.3)	3,005 (51.0)	<0.001
Low molecular weight heparin	545 (7.7)	156 (12.8)	389 (6.6)	<0.001
Unfractionated heparin	4,616 (64.9)	1,053 (86.4)	3,563 (60.5)	<0.001
Closure device	3,425 (48.3)	16 (1.3)	3,409 (58.0)	<0.001
Bare-metal stents used, n	0.3 ± 0.7	0.3 ± 0.7	0.3 ± 0.7	0.147
Drug-eluting stents used, n	1.1 ± 1.1	1.0 ± 1.0	1.1 ± 1.2	0.009
Total stents used, n	1.4 ± 1.1	1.4 ± 0.9	1.4 ± 1.1	0.073
Bleeding risk				
Probability, %	1.97 ± 1.71	1.62 ± 1.35	2.04 ± 1.76	<0.001
Risk level				<0.001
Low, <1%	2,292 (32.2)	469 (38.5)	1,823 (30.9)	
Moderate, 1%–3%	3,541 (49.7)	607 (49.8)	2,934 (49.7)	
High, >3%	1,288 (18.1)	143 (11.7)	1,145 (19.4)	

Values are mean ± SD or n (%).

CCS = Canadian Cardiovascular Society; NYHA = New York Heart Association; PCI = percutaneous coronary intervention; STEMI = ST-segment elevation myocardial infarction.

associated with TRI were mostly post-procedural, with a minimal contribution from procedural costs, and were principally driven by a major contribution from reduced LOS.

Clinical implications. In the United States, more than 600,000 PCI are performed annually (24). Assuming TRI use increases by 10%, from the current rate of 6.9% (25) (an annual increase of approximately 60,000 TRI procedures), U.S. hospitals could realize nearly $50 million in added savings, assuming our data ($800). For hospitals performing 1,000 PCI procedures annually, a 10% to 20% TRI adoption rate would imply incremental savings of $80,000 to $160,000 per year. These potential savings are meaningful, as hospitals modify staffing and post-PCI discharge patterns or initiate same-day discharge protocols.

Our study findings have even greater implications in the current era of ongoing healthcare reform. Payment reforms such as "per-episode" bundled payment and capitation, with global payments or accountable care organizations are currently under development and will likely replace the traditional fee-for-service payment system (26–33). It is thought that the strategies underlying accountable care organizations and episode bundles, which are being piloted as voluntary programs, will become a mandatory part of fee-for-service physician payment in Medicare (with a parallel program for hospitals termed "value-based purchasing")

Table 2. Length of Stay in All Patients and by Bleeding Risk as Estimated With the NCDR Model

	n	Radial	Femoral	Difference	p Value
Unadjusted					
All patients	7,121	2.49 (2.09 to 2.89)	2.98 (2.60 to 3.35)	0.49 (0.25 to 0.72)	<0.0001
Bleeding risk					
Low, <1%	2,292	2.14 (1.89 to 2.38)	2.45 (2.23 to 2.66)	0.31 (0.12 to 0.50)	0.0015
Moderate, 1% to 3%	3,541	2.72 (2.24 to 3.20)	2.88 (2.47 to 3.29)	0.16 (–0.20 to 0.52)	0.3814
High, >3%	1,288	3.04 (2.13 to 3.94)	4.02 (3.39 to 4.65)	0.98 (0.18 to 1.79)	0.0171
Adjusted*					
All patients	7,121	3.38 (2.92 to 3.83)	3.76 (3.32 to 4.20)	0.38 (0.12 to 0.64)	0.005
Bleeding risk					
Low, <1%	2,292	2.71 (2.18 to 3.24)	3.11 (2.59 to 3.63)	0.40 (0.22 to 0.57)	<0.001
Moderate, 1%–3%	3,541	3.42 (2.71 to 4.13)	3.51 (2.83 to 4.19)	0.09 (–0.37 to 0.55)	0.700
High, >3%	1,288	3.74 (2.92 to 4.56)	4.60 (3.84 to 5.35)	0.86 (0.25 to 1.46)	0.006

Values are odds ratios (95% confidence intervals). *Access site by bleeding interaction p = 0.048 with main effects included in the model.

NCDR = National Cardiovascular Data Registry.

Table 3. Total Unadjusted and Adjusted Hospital Cost Savings in All Patients and by Bleeding Risk as Estimated With the NCDR Model

	n	Radial	Femoral	Difference: Radial vs. Femoral	p Value
Unadjusted costs					
All patients	7,121	$14,441 ($12,281–$16,602)	$15,983 ($13,847–$18,118)	$1,541 ($1,052–$2,031)	<0.001
Bleeding risk					
Low, <1%	2,292	$13,919 ($11,866–$15,971)	$14,690 ($12,673–$16,708)	$771 ($156–$1,386)	0.014
Moderate, 1%–3%	3,541	$14,668 ($12,396–$16,940)	$15,983 ($13,759–$18,207)	$1,316 ($629–$2,003)	<0.001
High, >3%	1,288	$15,361 ($12,673–$18,049)	$17,749 ($15,423–$20,074)	$2,388 ($654–$4,121)	0.007
Adjusted costs					
All patients	7,121	$14,954 ($14,547–$15,383)	$15,784 ($15,463–$16,105)	$830 ($296–$1,364)	<0.001
Bleeding risk					
Low, <1%	2,292	$14,074 ($13,590–$14,575)	$14,716 ($14,234–$15,210)	$642 ($43–$1,242)	0.035
Moderate, 1%–3%	3,541	$15,161 ($14559–$15,824)	$15,867 ($15,388–$16,331)	$706 ($104–$1,308)	0.029
High, >3%	1,288	$16,115 ($14,899–$17,612)	$17,776 ($16,815–$18,814)	$1,621 ($271–$2,971)	0.038

Values are median (interquartile range).
NCDR = National Cardiovascular Data Registry.

(34). Our study shows substantial cost savings to hospitals with TRI and offers a solution for reducing costs of PCI, especially when combined with same-day discharge. The magnitude of cost savings is large and should be of considerable interest to policy makers, payers, and, most importantly, hospitals implementing TRI programs.

There were fewer bleeding complications associated with TRI in the present study, which is consistent with results from the RIVAL (Radial Versus Femoral Access for Coronary Angiography and Intervention in Patients With Acute Coronary Syndromes) study (5). Both the direction and magnitude of reduced bleeding in this study are also consistent with previous randomized and observational studies comparing TRI with TFI (5,6,8,13). Particularly noteworthy, the observed bleeding reduction in the TRI group was achieved despite frequent use of other bleeding avoidance strategies (e.g., 51% bivalirudin use, 58% closure devices) in the TFI group.

This study suggests that the major contributor to the cost savings of TRI is related to reducing LOS. This finding persisted despite only 4% of TRI patients being discharged the same day in our study. Lower bleeding rates only contributed marginally, and there was only a small contribution from reduced procedural costs. As hospitals increasingly use same-day discharge protocols (35–37) for TRI patients, LOS will expectedly decrease, and greater cost savings attributable to TRI will likely increase further (38).

Study limitations. First, the observational nature of these data may be subject to selection bias and unmeasured confounding, despite rigorous propensity score methods with IPW to adjust for confounding associated with TRI use. Given the nonrandomized nature of this study, an unmeasured confounder may have affected physician choice, both for the use of transradial or transfemoral access and the timing of discharge. Given that the TRI cohort was somewhat lower risk, physicians may be more apt to discharge patients earlier to home, which may partially account for the cost differences noted in this study. However, it should also be noted that when transfemoral patients are dismissed to home on the same day, it is likely that patients received a vascular closure device that would drive up procedurally related costs for the TFI cohort. Data from these hospitals may not be generalizable to other U.S. practices in the early stages of TRI adoption, given the expected learning curve associated with TRI (9,10,39), which is associated with higher rates of crossover and procedural failure. The cost savings may depend on either shortening the learning curve or not being fully realized until adequate learning has been achieved. To account for these limitations, we intentionally included data from 5 hospitals with varying PCI volumes and TRI expertise, a hierarchical modeling structure that adjusts for the effect of site, and bias-corrected bootstrap resampling to yield more generalizable costs for TRI and TFI. Third, the costs demonstrated here are from the hospital perspective. A broader societal-level perspective may be preferable, as downstream costs or savings associated with TRI are possible. We also chose not to provide an analysis from the payer's perspective, as hospital reimbursement for TRI and TFI are the same. Additionally, we did not capture crossover. Therefore, some variation may exist in reported rates of TRI and TFI where an operator switched access sites during a given procedure. Finally, we were unable to prospectively study quality of life data, which limits a more comprehensive cost-utility evaluation. However, because transradial access in general has been shown to result in

increased patient satisfaction, we believe any quality of life data would further favor TRI (4).

Conclusions

TRI is associated with significantly lower costs than is TFI when examined from a hospital perspective. Most of these cost savings were driven by reduced LOS during the post-procedural period, with lesser savings from reductions in bleeding. The magnitude of cost savings, which exceeded $800 per PCI, may be appealing to hospitals that consider adopting TRI for PCI.

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Key Words: catheterization ■ costs ■ femoral artery ■ outcomes ■ percutaneous coronary intervention ■ radial artery.

APPENDIX

For a supplemental figure, please see the online version of this paper.