ORIGINAL ARTICLE

Trends in Arterial Access Site Selection and Bleeding Outcomes Following Coronary Procedures, 2011–2018

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BACKGROUND: Prior studies of radial access for cardiac catheterization have focused on early adopters of the technique, and some have described a risk/treatment paradox of low radial access use among high bleeding risk patients. This study aimed to determine (1) trends in radial access use over time, (2) if increasing use of radial access is driven by new invasive and interventional cardiologists (operators) or existing operators changing their practice, and (3) if increasing radial rates are associated with lower bleeding rates and elimination of the risk/treatment paradox.

METHODS: In this cross-sectional study using data from the Clinical Assessment, Reporting, and Tracking Program, we calculated radial access rates and risk-adjusted postprocedural bleeding rates of patients undergoing diagnostic angiography or percutaneous coronary intervention (PCI) between 2011 and 2018 in Veterans Affairs hospitals. We used separate bleeding risk models for diagnostic angiography and PCI and assessed temporal trends with the Kendall Tau-b test.

RESULTS: Among 253,179 diagnostic angiograms and 93,614 PCIs, radial access rates increased over time for both diagnostic (17.5%–60.4%; \( P < 0.01 \)) and PCI procedures (14.0%–51.8%; \( P < 0.01 \)). Existing operators and new operators increased their use at similar rates, but new operators entered practice with higher baseline rates. Nearly all operators used radial access at least once in 2018. Overall adjusted rates of bleeding declined, a trend that was significant for diagnostic angiography (2.4%–1.4%, \( P = 0.02 \)) but not PCI (3.4%–2.5%, \( P = 0.20 \)). Femoral access patients had a higher predicted risk for bleeding.

CONCLUSIONS: A steady rise in radial access for diagnostic angiography and PCI was driven by increasing use among existing operators and high use by new operators. While this was associated with decreasing bleeding rates, a risk/treatment paradox for access site selection persists; patients at higher bleeding risk were still more likely to receive femoral access.

Key Words: angiography ◼ cardiac catheterization ◼ hospitals ◼ percutaneous coronary intervention ◼ Veterans
Previously demonstrated for access site selection. It has widespread use has altered the risk-treatment paradox of radial access has impacted bleeding rates, or if more recent use by existing operators. This was associated with decreasing bleeding rates, but a risk/treatment paradox persists.

WHAT THE STUDY ADDS

• In this cross-sectional study of Veterans Affairs patients from 2011 to 2018, a steady increase in radial access use was seen for both diagnostic angiography and percutaneous coronary intervention patients, driven by increasing use by existing and new operators. This was associated with decreasing bleeding rates, but a risk/treatment paradox persists.

Nonstandard Abbreviations and Acronyms

CART clinical assessment, reporting, and tracking program
PCI percutaneous coronary intervention
VA Veterans Affairs

that more contemporary practice patterns may reflect either equal rates of radial and femoral access or perhaps even a predominance of radial approach. This provides an opportunity to examine the diffusion of this novel practice into widespread use and determine where opportunities remain to increase radial access rates.

Veterans Affairs (VA) hospitals provide an ideal environment to evaluate these trends. It is unclear how rapidly radial access is being adopted VA if increasing use of radial access has impacted bleeding rates, or if more widespread use has altered the risk-treatment paradox previously demonstrated for access site selection. It is also unknown if increased radial rates are driven by recruitment of new cardiologists with greater skill with radial access or increased use by existing cardiologists. Therefore, we examined temporal trends in radial access rates and bleeding outcomes among patients monitored by the VA Clinical Assessment, Reporting, and Tracking (CART) Program. These results may inform ongoing efforts to promote radial access for diagnostic angiography and PCI, as well as provide a model for diffusion of other medical innovations.

METHODS

Because of the sensitive nature of the data collected for this study, requests to access the dataset from qualified researchers trained in human subject confidentiality protocols should be sent to the corresponding author. We conducted a retrospective analysis of all diagnostic coronary angiograms and PCIs performed in VA from 2011 to 2018. Cardiologists and procedures were identified through the CART Program, a mandatory quality and safety initiative for VA catheterization laboratories. Patient and procedural characteristics are entered prospectively by clinicians. CART is linked to VA administrative data to supplement clinical characteristics and presentation details, and we additionally obtained administrative codes and laboratory values to assess for postprocedural bleeding events, as described below. Details of the VA CART Program, including mechanisms to ensure data accuracy and validity, have been previously described. We had full access to the VA CART dataset. The VA Puget Sound Internal Review Board determined the present study to be exempt from need for oversight due to use of retrospective clinical data and that no informed consent was required.

The full data set included 264,604 diagnostic angiograms and 98,402 PCIs performed by 816 cardiologists at 83 VA hospitals. We then excluded procedures without a definitive access site indicator for radial or femoral angiograms and 3,743 PCIs, including cases with neither or both access sites (Figure S1). We first examined temporal trends, patient characteristics, and bleeding outcomes among the full population. Diagnostic angiography and PCI populations were considered separately.

To examine operator selection of access site, operators were assigned to a cohort based on and inclusive of the first year they performed a cardiac catheterization procedure within the VA Healthcare System: 2011 (or earlier), 2012, 2013, 2014, 2015, 2016, 2017, and 2018. Trends in access site use and bleeding rates were assessed for procedures performed by these operator cohorts.

Finally, for assessment of contemporary practice, we examined operators with at least 10 overall cases (diagnostic angiography and PCI) in 2018 and classified them by utilization of radial access among all 2018 cases. This included 332 operators performing 38,535 procedures (28,048 diagnostic angiograms and 10,487 PCIs). Arterial access site (radial versus femoral) was reported by the clinician in the procedural report. Postprocedure bleeding was defined as the occurrence, before discharge and within 72 hours, of (1) intracranial bleeding or cardiac tamponade with hemopericardium; or (2) hemoglobin drop of 3 g/dL or more; or (3) a blood transfusion.

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Patient and procedural characteristics, including demographics, comorbid conditions, and coronary anatomy, were compared for radial and femoral access patients with \( \chi^2 \) test for categorical variables and t tests for continuous variables. Subsequently, we presented patient and procedural characteristics by access site according to year of procedure performed.

We then plotted the proportion of procedures performed with radial or femoral access each year to illustrate overall access site trends by procedure type. Kruskal-Wallis tests were used to assess differences in radial and femoral access rates
over time for all operator cohorts. Generalized linear models were fit to estimate differences in radial access use by cohorts in their year of entry compared with Cohort 2011, as well as differences in relative slopes between the cohort-specific trend lines, with site included in the model as a fixed effect to account for hospital-level clustering.

We developed separate bleeding risk models for diagnostic and PCI procedures by fitting regression models, also including hospital site as a fixed effect, to estimate the predicted probability and adjusted rate of a postprocedure bleeding event. The diagnostic angiography model included age, sex, race, Hispanic ethnicity, diabetes, hyperlipidemia, hypertension, chronic kidney disease, current/former tobacco use, cerebrovascular disease, peripheral artery disease, chronic obstructive pulmonary disease, procedure indication (stable coronary artery disease, unstable angina, non–ST-segment-elevation myocardial infarction, ST-segment-elevation myocardial infarction, and other), status of procedure (elective, urgent, emergent, and salvage), number of obstructed coronary vessels, and cardiogenic shock. The PCI model included these variables in addition to indicators for staged PCI and procedural success. C statistics for the diagnostic angiography and PCI modes were 0.75 and 0.77, respectively.

We then calculated an expected bleeding rate for each procedure type by access site for each year of the study. An observed-to-expected ratio for bleeding and the risk-adjusted bleeding rate for each year of the study were then calculated overall and for both access sites separately. Predicted bleeding risk for radial and femoral were compared overall and for each year of the study using the \( \chi^2 \) test. The change in adjusted bleeding rates over time was assessed with the Kendall Tau-b test. Finally, we compared predicted bleeding risk and adjusted bleeding rates of high- and low radial utilizers in 2018 using \( \chi^2 \) tests.

## RESULTS

Among 253,179 diagnostic angiograms and 93,614 PCIs, radial access rates increased from 2001 to 2018 for both diagnostic (17.5%–60.4%; \( P < 0.01 \)) and PCI procedures (14.0%–51.8%; \( P < 0.01 \)). Compared with patients receiving femoral access, radial access patients were more likely to present for elective indications and were less likely to have comorbidities, such as diabetes, chronic kidney disease, and peripheral arterial disease (Tables 1 and 2). Overall patient characteristics showed only modest changes over time, with trends towards higher-risk presentations among patients treated with both radial and femoral access (Tables S1 through S4).

There was an overall decline in adjusted bleeding rate for angiography (2.3%–1.4%; \( P = 0.02 \); Figure 1A). For PCI, a decrease in adjusted bleeding was seen from 2011 to 2012, with subsequent flattening of the curve, overall showing a nonsignificant decline from 3.4% in 2011 to 2.5% in 2018 (\( P = 0.2 \); Figure 1B). For diagnostic angiograms, the adjusted rates of bleeding declined over time for both radial (2.4%–1.3%) and femoral procedures (2.4%–1.4%). For PCI, the adjusted rate of bleeding also declined modestly for both radial (2.4%–2.1%) and femoral procedures (3.5%–2.7%).

### Table 1. Patient Characteristics Associated With Femoral or Radial Access Use for Diagnostic Coronary Angiography, 2011–2018

| Characteristic                  | Femoral access (n=159,699) | Radial access (n=93,480) | \( P \) value |
|--------------------------------|---------------------------|-------------------------|--------------|
| Age, mean (SD)                 | 66.2 (9.13)               | 65.6 (9.08)             | <0.01        |
| Male                           | 97.4%                     | 97.0%                   | <0.01        |
| Race                           |                           |                         |              |
| White                          | 78.5%                     | 74.6%                   | <0.01        |
| Black                          | 15.3%                     | 18.7%                   |              |
| Asian                          | 0.4%                      | 0.6%                    |              |
| NA/AN                          | 0.9%                      | 0.9%                    |              |
| PI                             | 0.8%                      | 0.8%                    |              |
| Missing                        | 4.1%                      | 4.4%                    |              |
| Hispanic ethnicity             | 5.2%                      | 4.4%                    | <0.01        |
| Diabetes                       | 50.9%                     | 49.2%                   | <0.01        |
| Hyperlipidemia                 | 90.4%                     | 88.5%                   | <0.01        |
| Hypertension                   | 91.1%                     | 90.5%                   | <0.01        |
| CKD                            | 23.2%                     | 20.4%                   | <0.01        |
| Current/former tobacco use     | 65.7%                     | 67.9%                   | <0.01        |
| CVD                            | 21.2%                     | 18.0%                   | <0.01        |
| PAD                            | 23.5%                     | 21.4%                   | <0.01        |
| Chronic lung disease           | 25.4%                     | 25.4%                   | 0.77         |
| Procedural status              |                           |                         | <0.01        |
| Elective                       | 70.2%                     | 74.8%                   |              |
| Urgent                         | 24.9%                     | 21.9%                   |              |
| Emergent                       | 3.4%                      | 1.7%                    |              |
| Salvage                        | 0.1%                      | 0.0%                    |              |
| Indication                     |                           |                         | <0.01        |
| Acute coronary syndrome        | 23.1%                     | 19.6%                   |              |
| Stable CAD                     | 63.4%                     | 63.7%                   |              |
| Cardiomyopathy/heart failure   | 4.0%                      | 6.0%                    |              |
| Valvular heart disease         | 2.0%                      | 2.5%                    |              |
| Other                          | 3.1%                      | 3.2%                    |              |
| Missing                        | 4.5%                      | 5.0%                    |              |
| Coronary anatomy               |                           |                         | <0.01        |
| Normal                         | 8.0%                      | 11.6%                   |              |
| Nonobstructive CAD             | 16.3%                     | 21.2%                   |              |
| 1 vessel CAD                   | 22.8%                     | 24.5%                   |              |
| 2 vessel CAD                   | 17.3%                     | 15.6%                   |              |
| 3 vessel CAD                   | 27.3%                     | 17.7%                   |              |
| Missing                        | 7.6%                      | 9.1%                    |              |

AN indicates Alaskan Native; CAD, coronary artery disease; CKD, chronic kidney disease; CVD, cerebrovascular disease; NA, Native American; PAD, peripheral arterial disease; and PI, Native Hawaiian or other Pacific Islander.

The predicted bleeding risk, calculated from clinical and presentation factors, was higher for femoral access patients overall (diagnostic angiography 1.9% versus 1.4%, \( P < 0.01 \); and PCI 2.6% versus 2.0%, \( P < 0.01 \)), and in each year of the study, compared with radial access patients (Tables S1 through S4). Most annual operator cohorts entered with higher rates of radial access than preceding cohorts (Figure 2A).
and 2B). Using the radial rate of operators from Cohort 2011 in each year as a comparison, all subsequent cohorts entered at a higher rate for both diagnostic angiography and PCI. For diagnostic angiography, this higher rate was statistically significant for Cohorts 2012, 2015, and 2016 ($P<0.01$). For PCI, Cohorts 2016, and 2017 demonstrated significantly higher rates ($P<0.01$). Radial access rates increased for all cohorts over time; the slope of increase was not significantly different between cohorts for either diagnostic angiography ($P=0.70$) or PCI ($P=0.40$). Among 164 operators in the earliest cohort (Cohort 2011) who continued practice into 2018, 51 had high radial utilization ($\geq 75\%$), 59 had moderate radial utilization (26%–74%), and 54 had low radial utilization ($\leq 25\%$).

In the last year of the study (2018), among 332 operators performing 28,048 diagnostic and PCI procedures, there was a wide distribution of operator-level radial access rates (Figure 3). Nearly all operators used radial access at least once, 25% of operators used radial in 25% or less of their cases (low utilizers), and 41% used radial for 75% or greater of their cases (high utilizers). Compared with high radial utilizers, low utilizers were more likely to care for patients with acute presentations and with multivessel coronary artery disease, although overall differences were modest (Table S5). Low utilizers treated a population with modestly higher predicted bleeding risk for diagnostic angiography (1.9% versus 1.3%, $P<0.01$) but similar for PCI (3.1% versus 2.3%, $P=0.1$) compared with high utilizers. After adjustment, the bleeding rate was significantly worse for low radial utilizers for both diagnostic angiography (1.9% versus 1.2%, $P<0.01$) and PCI (3.9% versus 2.1%, $P<0.01$).

### DISCUSSION

As a model for the diffusion of a medical technology into widespread clinical practice, this study of radial access uptake in the VA has several interesting findings. Use of radial access increased both among operators new to the

| Femoral access | Radial access | $P$ value |
|---------------|--------------|-----------|
| Age, mean (SD) | 67.0 (9.00)  | 66.5 (8.79) | <0.01 |
| Male | 98.5% | 98.3% | 0.29 |
| Race | | | <0.01 |
| White | 81.1% | 77.8% | |
| Black | 12.6% | 15.7% | |
| Asian | 0.5% | 0.6% | |
| NA/AN | 0.9% | 0.9% | |
| PI | 0.8% | 0.8% | |
| Missing | 4.1 | 4.3% | |
| Hispanic ethnicity | 5.4% | 4.4% | <0.01 |
| Diabetes | 54.0% | 52.2% | <0.01 |
| Hyperlipidemia | 93.1% | 92.0% | <0.01 |
| Hypertension | 92.7% | 92.6% | 0.57 |
| CKD | 26.1% | 22.9% | <0.01 |
| Current/former tobacco use | 67.4% | 71.0% | <0.01 |
| CVD | 23.9% | 20.4% | <0.01 |
| PAD | 27.7% | 25.0% | <0.01 |
| Chronic lung disease | 27.4% | 27.1% | 0.41 |
| PCI indication | | <0.01 |
| Stable angina | 28.5% | 28.2% | |
| Unstable angina | 16.4% | 17.2% | |
| NSTEMI | 21.6% | 21.2% | |
| STEMI | 6.1% | 3.9% | |
| Other chest pain | 11.4% | 13.2% | |
| Other indication | 13.6% | 14.6% | |
| Missing | 2.4% | 1.7% | |
| Cardiogenic shock | 0.7% | 0.1% | <0.01 |
| Procedure status | | <0.01 |
| Elective | 63.7% | 66.2% | |
| Urgent | 28.5% | 28.7% | |
| Emergent | 6.4% | 3.9% | |
| Salvage | 0.2% | 0.1% | |
| Missing | 1.3% | 1.1% | |
| Coronary anatomy | | <0.01 |
| 1V CAD | 30.3% | 40.1% | |
| 2V CAD | 23.7% | 25.8% | |
| 3V CAD | 25.6% | 14.4% | |
| Other | 2.5% | 3.2% | |
| Missing | 17.9% | 16.5% | |
| Highest risk segment | | <0.01 |
| Left main | 4.6% | 2.1% | |
| Proximal LAD | 14.4% | 16.0% | |
| All other segments | 70.8% | 77.5% | |
| Missing | 10.2% | 4.5% | |
| Bifurcation treated | 9.9% | 10.5% | 0.02 |

(Continued)
VA and the existing operators with low baseline use, until almost all operators used radial access at least occasionally. By 2018, radial was the dominant access site in VA, with an associated decrease in postprocedural bleeding rates. However, radial access for PCI achieved 50% utilization 26 years after the technique was first described and 7 years after inclusion in clinical society guidelines. The US lagged significantly behind operators in Europe. Even in 2018, a third of operators remained femoral dominant. Despite more widespread use of radial access, a risk-treatment paradox persists; patients at higher risk for bleeding were still more likely to receive femoral access. Opportunities remain to shorten the medical innovation diffusion curve and benefit high-risk patients.

Clinical research commonly focuses on studies that establish the feasibility and efficacy of novel therapies. Less is known about patterns of diffusion to the larger body of clinicians. Many studies have confirmed a prolonged delay from evidence-based guidelines to implementation in practice, as well as marked heterogeneity in hospital and clinician uptake. The initial uptake of radial access in the United States among early adopters has been well described, including a learning curve that must be overcome by individual clinicians. We found that radial access subsequently achieved dominant use in VA by consistent uptake among nearly all operators, even those who were previously femoral dominant. VA operators surveyed in 2013, when radial access rates for PCI were only 21%, overall agreed that radial access was superior to femoral access for patient outcomes and noted only minor concerns about transitioning to a radial-dominant practice. Therefore, this population was primed for the subsequent learning effect we observed, with most existing operators achieving a radial-dominant practice by 2018.

A cohort effect was also seen, with most new cohorts of physicians entering VA practice with higher use of radial

Figure 1. Adjusted bleeding rates over time for patients undergoing cardiac procedures at Veterans Affairs hospitals from 2011-2018. A) Diagnostic coronary angiography. B) Percutaneous coronary intervention.
access than the preceding cohort. This effect, potentially driven by exposure to radial access during fellowship training for many new operators, emphasizes the importance of training programs for diffusion of innovation. Additionally, the movement of operators between hospitals may be important for dissemination of novel practices.

A quarter of all operators continued to use radial access for 25% or fewer of their procedures in 2018. These operators were predominately from the first operator group, Cohort 2011 and treated a population at higher risk of bleeding. Adjusted bleeding rates were significantly higher among this group compared with high radial utilizers, presenting a potential opportunity for quality improvement. However, nearly all operators in our cohort used radial access at least once in 2018; therefore, lack of knowledge or equipment may no longer

Figure 2. Radial access rates by annual cohort of operators. Operators were grouped by the first year performing A) diagnostic coronary angiography or B) percutaneous coronary intervention in Veteran Affairs hospitals, 2011-2018.
be significant barriers to use, and providing additional evidence-based data is unlikely to drive uptake. Interventions to increase radial use among these low utilizers may need to focus on building confidence with the technique and expanding use of radial access to more challenging anatomy.13

Prior studies have shown a marked risk-treatment paradox, where patients with the highest likelihood of benefiting from a bleeding reduction strategy are least likely to receive it.16,25 Our data demonstrate that this effect persists even as radial access is more commonly used. While some appropriate use of femoral access may be expected (harvested or injured radial arteries, need for large-bore access, or increased guide support for complex PCI), this is unlikely to fully account for the risk-treatment paradox in our data. Instead, risk factors for bleeding, such as age, peripheral vascular disease, and ST-segment-elevation myocardial infarction, may also increase the real or perceived technical challenges with using radial access. Continued improvement may require new strategies to increase operator confidence with radial access for emergent, high-risk and complex procedures, including coaching and peer support.26 Pre-procedural assessment of bleeding risk may encourage operators to better match access site to bleeding risk.27,28

Finally, there was a notable decline in bleeding complications for patients receiving radial and femoral access over this period. This may reflect increasing attention to bleeding risk and use of safe femoral techniques.29 While this is an encouraging trend for patients who cannot receive radial access, radial access remains the preferred access site, supported by multiple randomized trials.10 Ideally, bleeding rates will remain low for both access sites as radial continues to gain popularity in the cardiology community.

While we have seen a linear increase in radial use in VA since 2007, the shape of the diffusion curve going forward is unknown. If low utilizers are unwilling or unable to transition to radial-dominant practice, then the curve may plateau as femoral operators are gradually replaced by new radial-dominant operators. If all operators increase their use, including for complex and high-risk coronary procedures, then radial access may achieve near universal use, as demonstrated by some operators in our study with >90% utilization.

Our study is observational and cannot determine which strategies have led to the increased uptake of radial access. The population is limited to Veterans, includes few women, and acute coronary syndrome presentation is less common compared with non-VA populations, which may limit generalizability. Prior studies have indicated women, and patients with acute coronary syndrome are less likely to receive radial access for PCI, although potentially more likely to benefit.12,30 It is, therefore, possible that our study underestimates the association of radial access with bleeding rates in non-VA populations. Our bleeding outcome was based on laboratory values and administrative codes and may differ from other bleeding definitions using clinical adjudication. We anticipate that access site hematomas may be poorly captured by our definition, so our analysis may underestimate the benefit of radial access for reduction of clinically significant bleeding, compared with alternative definitions such as the Bleeding Academic Research Consortium definition. Our adjustment model did not include some variables that have been shown to be associated with high bleeding risk, including coagulopathy and use of oral anticoagulants. However, the model had good discrimination in this population. We were also unable to assess vascular complications of
CONCLUSIONS

A steady rise in radial access use for diagnostic angiography and PCI was driven by increased use among former femoral operators and high use by new operators. While this has been accompanied by a decline in bleeding rates, a risk-treatment paradox for access site selection persists. Future interventions to promote radial access should focus on expanding use to higher-risk populations with the most potential benefit from a bleeding reduction strategy.

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10.1016/j.jacc.2013.08.1651

10.1016/j.jacc.2013.08.1651

REFERENCES

1. Rao SV, Cohen MG, Kandzari DE, Bertrand OF, Gilchrist IC. The transradial approach to percutaneous coronary intervention: historical perspective, current concepts, and future directions. J Am Coll Cardiol 2010;55:2187–2195. doi: 10.1016/j.jacc.2010.01.039

2. Kolakkal AA, Alreshq RS, Muhammed AM, Zahran ME, Anas El-Wegoud M, Nabhan AF. Transradial versus transfemoral approach for diagnostic coronary angiography and percutaneous coronary intervention in people with coronary artery disease. Cochrane Database Syst Rev. 2018;4:CD012318. doi: 10.1002/14651858.CD012318.pub2

3. Kolm MM, Weernink MGM, von Birgelen C, Fens A, van der Heijden LC, van Til JA. Patient preference for radial versus femoral vascular access for elective coronary procedures: The PREVAS study. Catheter Cardiovasc Inter. 2018;91:17–24. doi: 10.1002/ccd.27039

4. Amin AP, House JA, Safety DM, Chhatwalwaik AK, Giersiefen H, Bremer A, Hamon M, Baklanov DV, Aluko A, Wohrs Q, et al. Costs of transradial percutaneous coronary intervention. JACC Cardiovasc Interv. 2013;6:827–834. doi: 10.1016/j.jcin.2013.04.014

5. Campeau L. Percutaneous radial access coronary artery angiography. Cathet Cardiovasc Diagn. 1989;163–7. doi: 10.1002/ccd.1810160103

6. Bernat I, Horak D, Stasek J, Matys M, Pesek J, Ostadal P, Hrabos V, Dusek J, Koza J, Sembera Z, et al. ST-segment elevation myocardial infarction treatment by radial or femoral approach in a multicenter randomized clinical trial: the STEMI-RADIAL trial. J Am Coll Cardiol. 2014;63:964–972. doi: 10.1016/j.jacc.2013.08.1651

7. Jolly SS, Yusuf S, Cairns J, Niemelä K, Xavier D, Widmsky P, Budaj A, Niemelä M, Valentin V, Lewis BS, et al. RIVAL trial group. Radial versus femoral access for coronary coronary syndromes (RIVAL): a randomised, parallel group, multicentre trial. Lancet 2011;377:1409–1420. doi: 10.1016/S0140-6736(11)60404-2

8. Romagnoli E, Biondi-Zocca G, Scialbasi A, Politi L, Rigatelli S, Pendenza G, Summaria F, Patrizi R, Borghi A, Di Russo C, et al. Radial versus femoral randomized investigation in ST-segment elevation acute coronary syndrome: the RIFLE-STEACS (Radial Versus Femoral Randomized Investigation in ST-Elevation Acute Coronary Syndrome) study. J Am Coll Cardiol. 2012;59:2024–2035. doi: 10.1016/j.jacc.2012.06.017

9. Valgimigli M, Gagnor A, Calabrò P, Frigoli E, Leonardi S, Zaro T, Rubartelli P, Briguori C, Andò G, Repetto A, et al. MATRIX Investigators. Radial versus femoral access in patients with acute coronary syndromes undergoing invasive management: a randomised multicentre trial. Lancet 2015;385:2465–2476. doi: 10.1016/S0140-6736(15)60292-6

10. Ferrante G, Rao SV, Jüni P, Da Costa BR, Reimers B, Condorelli G, Anzuini A, Jolly SS, Bertrand OF, Krauss MW, et al. Radial versus femoral access for coronary interventions across the entire spectrum of patients with coronary artery disease: a meta-analysis of randomized trials. JACC Cardiovasc Interv. 2016;9:1419–1434. doi: 10.1016/j.jcin.2016.04.014

11. Gutierrez A, Tsai TT, Stanislawski MA, Vidovich M, Bryson CL, Bhatt DL, Grunkwald GK, Rumsfeld J, Rao SV. Adoption of transradial percutaneous coronary intervention and outcomes according to center radial volume in the Veterans Affairs Healthcare System: insights from the Veterans Affairs clinical assessment, reporting, and tracking (CART) program. Circ Cardiovasc Interv. 2013;6:336–346. doi: 10.1161/CIRCINTERVENTIONS.113.001110

12. Feldman DN, Swaminathan RV, Kaltenbach LA, Baklanov DV, Kim LK, Wong SC, Minutoli RM, Messenger JC, Moscow I, Garratt KN, et al. Adoption of radial access and comparison of outcomes to femoral access in percutaneous coronary coronary intervention: an updated report from the national cardiovascular data registry. (2007-2012). Circulation. 2013;127:2295–2306. doi: 10.1161/CIRCULATIONAHA.112.000536

13. Hess CN, Peterson ED, Neely ML, Dai D, Hilligsee WB, Kruckoff MW, Kuchter MA, Messenger JC, Pancholy S, Plana RN, et al. The learning curve for transradial percutaneous coronary intervention among operators in the United States: a study from the National Cardiovascular Data Registry. Circulation. 2014;129:2277–2286. doi: 10.1161/CIRCULATIONAHA.113.006386

14. Waldo SW, Goekhale M, O’Donnell CI, Plomondon ME, Valle JA, Armstrong EJ, Schofield R, Fihn SD, Maddox TM. Temporal trends in coronary angiography and percutaneous coronary intervention: insights from the VA clinical assessment, reporting, and tracking program. JACC Cardiovasc Interv. 2018;11:879–888. doi: 10.1016/j.jcin.2018.02.035

15. Amin AP, Miller S, Rahn B, Caruso M, Pierce A, Sorensen K, Kurz H, Jolly SS, Yusuf S, Cağrıs D, Singh J, et al. Reversing the “Risk-Treatment Paradox” of bleeding in patients undergoing percutaneous coronary intervention: risk-concordant use of bleeding avoidance strategies is associated with reduced bleeding and lower costs. J Am Heart Assoc. 2018;7:e008551. doi: 10.1161/JAHA.118.008551

16. Marso SP, Amin AP, House JA, Kennedy KV, Speterus JA, Rao SV, Cohen DJ, Messenger JC, Rumsfeld JS. National Cardiovascular Data Registry. Association between use of bleeding avoidance strategies and risk of peri-procedural bleeding in patients undergoing percutaneous coronary intervention. JAMA. 2010;303:2156–2164. doi: 10.1001/jama.2010.708

17. Byrd JB, Vigen R, Plomondon ME, Rumsfeld J, Box TL, Fihn SD, Maddox TM. Data quality of an electronic health record tool to support VA cardiac catheterization laboratory quality improvement: the VA Clinical
Assessment, Reporting, and Tracking System for Cath Labs (CART) program. *Am Heart J.* 2013;165:434–440. doi: 10.1016/j.ahj.2012.12.009

18. Levine GN, Bates ER, Blankenship JC, Bailey SR, Bittl JA, Cercek B, Chambers CE, Ellis SG, Gutyay RA, Hollenberg SM, et al. 2011 ACCF/AHA/SCAI guideline for percutaneous coronary intervention: executive summary: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Society for Cardiovascular Angiography and Interventions. *Circulation.* 2011;124:2574–2609. doi: 10.1161/CIR.0b013e31823a5596

19. Mamas MA, Nolan J, de Belder MA, Zaman A, Kinnaird T, Curzen N, Kwok CS, Buchan I, Ludman P, Kontopantelis E; British Cardiovascular Intervention Society (BCIS) and the National Institute for Clinical Outcomes Research (NICOR). Changes in arterial access site and association with mortality in the United Kingdom: observations from a National Percutaneous Coronary Intervention Database. *Circulation.* 2016;133:1656–1667. doi: 10.1161/CIRCULATIONAHA.115.018083

20. Chan WV, Pearson TA, Bennett GC, Cushman WC, Gaziano TA, Gorman PN, Handler J, Krumholz HM, Kushner RF, MacKenzie TD, et al. ACC/AHA special report: clinical practice guideline implementation strategies: a summary of systematic reviews by the NHLBI Implementation Science Work Group: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *J Am Coll Cardiol.* 2017;69:1076–1092. doi: 10.1016/j.jacc.2016.11.004

21. Cabana MD, Rand CS, Powe NR, Wu AW, Wilson MH, Abboud PA, Rubin HR. Why don't physicians follow clinical practice guidelines? A framework for improvement. *JAMA.* 1999;282:1458–1465. doi: 10.1001/jama.282.15.1458

22. Smailowitz NR, Mohananey D, Razzouk L, Weisz G, Slater JN. Impact and trends of intravascular imaging in diagnostic coronary angiography and percutaneous coronary intervention in inpatients in the United States. *Catheter Cardiovasc Interv.* 2018;92:E410–E415. doi: 10.1002/ccd.27673

23. Keach JW, Stanislavski MA, Barón AE, Plomondon ME, Langner PR, Amin A, Gilmarin HM, Waldo S, Maddox TM. Variation in contrast-associated acute kidney injury prophylaxis for percutaneous coronary intervention: insights from the Veterans Affairs Clinical Assessment, Reporting, and Tracking (CART) program. *BMC Nephrol.* 2020;21:150. doi: 10.1186/s12882-020-01802-z

24. Helfrich CD, Tsai TT, Rao SV, Lemon JM, Eugenio EC, Vidovich MI, Shroff AR, Speiser BS, Bryson CL. Perceptions of advantages and barriers to radial-access percutaneous coronary intervention in VA cardiac catheterization laboratories. *Cardiovasc Revasc Med.* 2014;15:329–333. doi: 10.1016/j.carrev.2014.08.006

25. Wimmer NJ, Resnic FS, Mauri L, Matheny ME, Plemontec E, Ho KK, Robbins SL, Waldman HM, Yeh RW. Risk-treatment paradox in the selection of transradial access for percutaneous coronary intervention. *J Am Heart Assoc.* 2013;2:e000174. doi: 10.1161/JAHA.113.000174

26. Prabhu KM, Don C, Sayre GG, Kearney KE, Hira RS, Waldo SW, Rao SV, Au DH, Doll JA. Interventional cardiologists’ perceptions of percutaneous coronary intervention quality measurement and feedback. *Am Heart J.* 2021;235:97–103. doi: 10.1016/j.ahj.2021.01.019

27. Doll JA, O’Donnell CL, Plomondon ME, Waldo SW. Development and implementation of an in-hospital bleeding risk model for percutaneous coronary intervention. *Cardiovasc Revasc Med.* 2021;28:20–24. doi: 10.1016/j.carrev.2020.07.033

28. Rao SV, McCoy LA, Spertus JA, Krone RJ, Singh M, Fitzgerald S, Peterson ED. An updated bleeding model to predict the risk of post-procedure bleeding among patients undergoing percutaneous coronary intervention: a report using an expanded bleeding definition from the National Cardiovascular Data Registry CathPCI Registry. *JACC Cardiovasc Interv.* 2013;6:897–904. doi: 10.1016/j.jcin.2013.04.016

29. Ben-Dor I, Sharma A, Rogers T, Yerasi C, Case BC, Chezar-Azerrad C, Musallam A, Forestal BJ, Zhang C, Hashim H, et al. Micropuncture technique for femoral access is associated with lower vascular complications compared to standard needle. *Catheter Cardiovasc Interv.* 2021;97:1379–1385. doi: 10.1002/ccd.29330

30. Di Santo P, Simard T, Wells GA, Jung RG, Ramirez FD, Boland P, Marbach JA, Parlow S, Kyeremanteng K, Coyle D, et al. Transradial versus transfemoral access for percutaneous coronary intervention in ST-segment-elevation myocardial infarction: a systematic review and meta-analysis. *Circ Cardiovasc Interv.* 2021;14:e009994. doi: 10.1161/CIRCINTERVENTIONS.120.009994