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Diffusion of Procedure Innovation Among Cardiac Catheterization Operators at the Veterans Health  
Administration

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**Abstract**

Diffusion of Procedure Innovation Among Cardiac Catheterization Operators at the Veterans Health Administration

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This research is an important first step in understanding the role of physicians as front-line adopters of innovative cardiac intervention procedures. Previous research has demonstrated that innovative coronary intervention procedures are adopted at different rates across Veterans Health Administration (VHA/VA) hospitals and remains unclear about what drives this difference. For example, interventions can occur via the femoral or radial artery, yet the novel radial-access method is unevenly adopted. Clinical decisions by interventional cardiologists (i.e., operators) in community hospitals have been shown to vary widely even within the same facility, suggesting operators as drivers of adoption. A prevailing hypothesis in implementation theory is that social networks play a role in individuals conforming to dominant norms via interpersonal influences. To our knowledge, no study has examined conformity among operator use of innovative coronary procedures or how much variation is attributable to patients, individual operators, or hospitals within VHA. This retrospective analysis of all diagnostic and interventional cardiac catheterizations between June 2011 and March 2021, based on the VA Clinical Assessment Reporting and Tracking Program (CART), sought to:

- Aim 1: Determine the variation in adoption of 4 innovative coronary intervention procedures attributable to hospital, operator, and patient. Random-effects models were used to quantify patient, clinician, and hospital-level variability.

- Aim 2: Assess if early career interventional cardiologists (i.e., operators practicing for less than 5 years since clinical fellowship training) are more likely to perform innovative procedures. We used logistic regression models to estimate the association between being an early-stage career operator and innovation adoption.

- Aim 3: Determine how the arrival of a radial-dominant operator affects the use of the trans-radial approach among existing operators in a hospital. We used mixed-effects logistic regression to estimate the association between being in a hospital exposed to a radial-dominant operator and use of radial-access.

Findings from this research provide preliminary evidence to support strategies for improved implementation of innovative, recommended, and/or evidence-based care and ultimately, a medical culture that can integrate new ideas and dynamics to achieve sustained change.

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## **DEDICATION**

To Jules and Bran: I would have never made it this far without your unconditional love, support, and mentoring. To Ayra & Nala: Your purrs and demanding meows kept me sane, laughing, and writing. To Bexley: The reprieve, bright light, and bonafide clearing in the thick woods that carried me to the finish.

## INTRODUCTION

In the Diffusions of Innovation (DOI) literature, an *innovation* is a newly perceived practice. This perception of newness can be defined by an individual, organization, or any large entity, which then becomes the *unit* of adoption.<sup>1</sup> The definition of an innovation is focused less on the objective novelty of the practice but rather the subjective one. In other words, an idea or practice may have existed for a long time, yet this does not preclude it from being defined as an innovation even if there is a delay until the unit of adoption learns about, is persuaded by, and/or decides to adopt it. In contrast, *evidence-based healthcare* is a concept that integrates clinical expertise (i.e., experience with patients over time), and external evidence that may be generated from randomized controlled trials and other rigorous and robust research methodology.<sup>2</sup> It refers to the use of the most up-to-date data in making patient-care decisions and the expectation that scientific evidence should be the ultimate deciding factor—overriding a clinician’s experience and intuition—in care delivery.<sup>3</sup> Provider decisions are reflected in the innovations and/or evidence-based practices their patients receive.

In this body of work, we applied the concepts of innovation adoption to physicians employed by the Veterans Health Administration (VA). Specifically, we studied interventional cardiologist operators working in cardiac catheterization laboratories in VA hospitals across the United States. Interventional cardiology, like other areas of the US health care system<sup>10-14</sup>, has seen wide variation in the implementation of evidence-based practices and innovative new procedures intended to increase efficiency, reduce costs, and improve quality of care and patient outcomes.<sup>15-17</sup> The result is a disparity in patients receiving innovative and potentially higher quality care, despite efforts to ensure quality improvement throughout a health system.

VHA implemented a novel electronic health record (EHR) tool called Clinical Assessment Reporting and Tracking (CART) in 2005 as one of these quality improvement efforts. CART is a national quality and safety program for invasive cardiovascular procedures in VA. Past efforts to disseminate

innovative cardiac treatment in the VA system occurred primarily through a research group established with the express purpose of discovering and incorporating quality improvement ideas and initiatives in VA. This Quality Enhancement Research Initiative (QUERI) was established 1998 with different groups focusing on important areas of interest for the VA patient population. The Ischemic Heart Disease (IHD) QUERI was focused specifically on diseases of the heart. The agenda for these research groups varied across topics; however, they had the common goal of “decreasing the time from generation of research findings for interventions deemed a national priority to their use by VA providers”.<sup>18</sup> Even so, there have been limited efforts to disseminate innovative cardiac treatment in the VA system through this group. National quality and safety programs such as CART offer a unique opportunity to explore potential factors associated with the procedures patients receive, care delivery, and ultimately, the diffusion of medical innovations.

CART captures procedure information for each cardiac catheterization laboratory (cath lab). In this work, we assessed four cardiac catheterization laboratory (cath lab) procedures with varying levels of accumulating evidence and support that are readily captured in CART. They include: (1) Trans-radial access (TRA), (2) Atherectomy, (3) Intravascular ultrasound (IVUS & OCT), and (4) Fractional flow reserve (FFR/iFR). *Trans-radial access* is the primary access method during coronary intervention procedures in many countries.<sup>19,20</sup> Scientific evidence supporting its benefits has existed for over 20 years and a 2015 report officially recommended it as the default access method.<sup>21</sup> TRA at this point is therefore a current and evidence-based practice. It is an innovation to the extent that there are still many practitioners and organizations that have not yet been persuaded to adopt it. In other words, it can also be defined as an innovation if a prospective adopter finally becomes aware of its benefits and is persuaded to adopt it. As such, TRA is both innovative and evidence based. *Atherectomy*, or rotational atherectomy as it is formally called, is an approach that has existed since 1988;<sup>22</sup> however, unlike TRA, the evidence and scientific support for its clinical benefits is still being amassed. There is promising research suggesting it facilitates success rates of complex PCI procedures<sup>23</sup>, but the impact on patient outcomes, especially those with stent placement is not conclusive yet.<sup>24</sup> Atherectomy therefore is an innovation with a developing

evidence base. Use of *intravascular ultrasound (IVUS)* and its analog *optical coherence tomography (OCT)* guidance for arterial access (radial or femoral) has been conclusively shown to improve patient outcomes<sup>25,26</sup> therefore making it concretely an evidence-based innovation. Despite this, it remains underused in many cath labs,<sup>24</sup> suggesting it has yet to be fully adopted by the providers and organizations at the cath labs that don't currently employ it. *Fractional flow reserve (FFR)* is another imaging technique that, like IVUS, adds anatomic and physiologic data concerning the state of lesions in a patient, to help a clinician decide about intervening on potentially complex lesions. Long-term data has also shown that FFR-guided decision-making helps reduce unnecessary interventions for patients and overall improved outcomes<sup>27</sup> making FFR, like IVUS, a well-supported evidence-based practice. Its lack of use in cath labs to date suggest it is still novel to many practitioners and therefore also an innovation.

Assimilation of new knowledge that leads to changes in medical practice is characterized as a constant process that individuals perform. This includes activities such as consistently scanning the scientific literature and being an active and engaged consumer of data from national conferences.<sup>1</sup> Individuals are then thought to share and implement what they learn, dissemination therefore an ongoing and relatively linear process. Though it is true that some of this does occur, the reality is increasing difficulty for physicians to 'keep up' with evidence. Also, the flow from knowledge generation to consumption and dissemination is not as linear of a process as it has and continues to be portrayed. The conceptual framework underpinning this body of work (Figure 1) introduces and places weight on additional complex social factors that I believe play a role in what is ultimately decided in day-to-day clinical practice. I propose that understanding more about how that process occurs could pave the road to increased use of evidence-based medicine and can help us understand why some of the implementation-of-innovation models that exist are not as effective in practice. These findings would thus inform efforts outside of the VA cath lab and increase the use of evidence-based medicine in general.

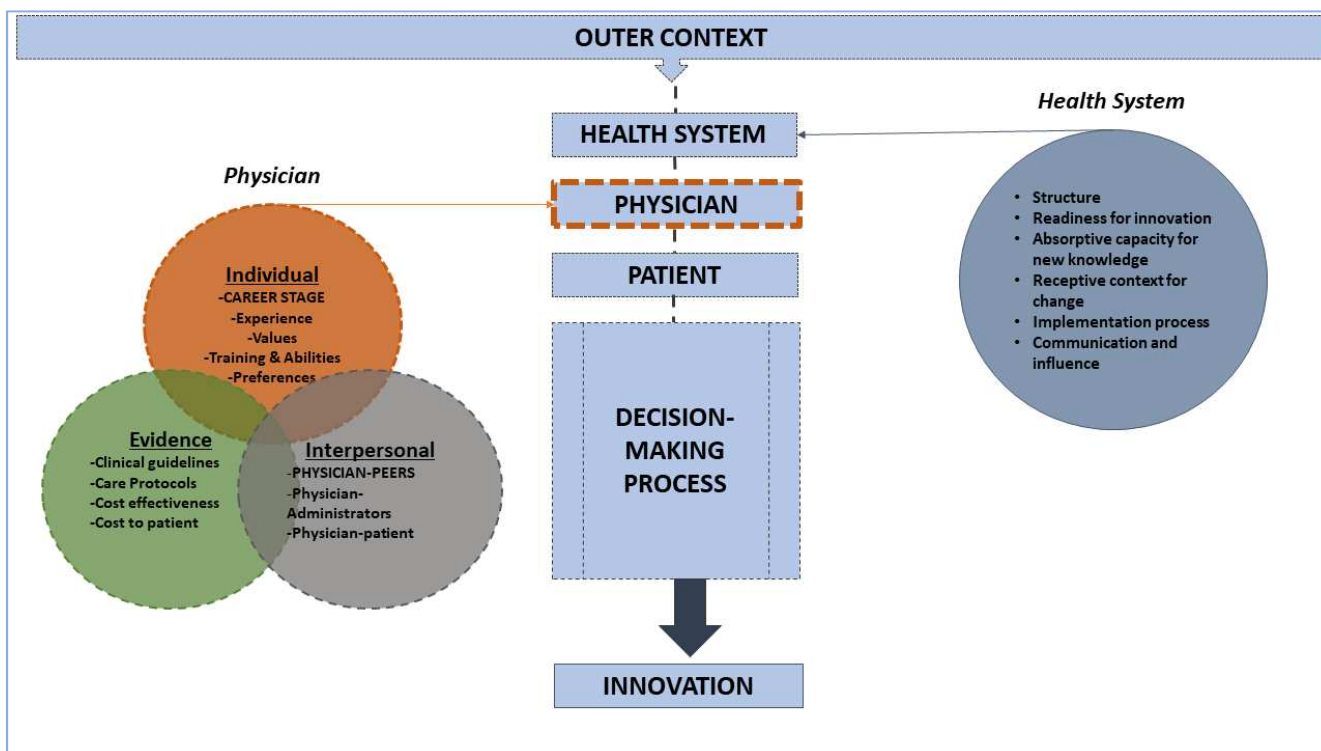


Figure 1: Conceptual Model

This study drew on the factors identified by Manja et al. (2019) as major determinants of practice for cardiologist physicians.<sup>30</sup> Through a descriptive qualitative study, Manja et al. concluded that clinical decision making by cardiologists is influenced by individual and interpersonal factors. In our model, we place physicians and three main spheres of influence—scientific evidence, individual, and interpersonal factors—at the center of decision making for a patient within a hospital (Figure 1). The hospital is depicted as further nested within the larger sociopolitical context, or region, in the context of this study. The *evidence* sphere of influence is comprised of clinical guidelines, care protocols, cost effectiveness analyses, and costs to patients that physicians consider when making a clinical decision. The *individual* and *interpersonal* spheres are components of physician social climate. The individual sphere of influence includes physician experience, values, preferences, training, and abilities. The interpersonal sphere of influence contains physician-peer, physician-administrator, and physician-patient relationships that physicians regularly engage in. We build on the model set forth by Manja et al. and add *career stage* as an

additional individual-level factor that comprises the physician's social climate. We posit that career stage, especially being an early-stage practitioner, is associated with the clinical decision to adopt innovative procedures. For example, it is possible that clinical fellowship provided training on a new procedure and by virtue of being fresh out of training (i.e., early-career), an operator would retain this new mode of practice given their recent preparation. This research also explores the physician-peer dynamic, specifically exposure to a peer with a dominant practice norm at the physician interpersonal level that might be driving clinical decisions to adopt innovative procedures. Exposure to a peer with a principal mode of practice might be expected to exert some type of influence—peer influence—that could have implications for individual-level decisions, especially if that individual is inclined to conform to dominant norms. It is also possible that a peer with a dominant or favored mode of practice is likely to provide the most technical support for it. In other words, a physician-peer uncertain about a novel methodology, would gain exposure to a more confident and proficient peer, in turn making them more confident and less uncertain about the technique given the additional guidance and training by the peer with dominant norm. This model also accounts for health system-level factors that could form part of how a system may disseminate innovative treatments and procedures. It does this by illustrating decision making as a process influenced by (a) the outer context (e.g., overarching sociopolitical climate), (b) the health system, and (c) physicians (i.e., operators), and (d) patients. Importantly, it parses out these levels of influence in a way that allows us to ask the question: How much does each level contribute to the overall decision? And supports our goal to understand innovation adoption across these levels for different innovations.

This research is an important first step in understanding the potential role of physicians as front-line adopters of innovative cardiac intervention procedures and how decisions to provide innovative treatment may be transmitted—explicitly or implicitly—through individual and organizational networks. Practice-based research networks create a new information and skill exchange between innovative research hubs and community providers.<sup>31</sup> We predict a similar effect from the arrival of a TRA-dominant operator at a non-TRA dominant hospital (Aim 3). Through this approach we aimed to characterize if the arrival of a new operator with a specific practice preference is associated with the uptake of that

preference by existing peers in the hospital. The goal is to describe peer influence and homophily, defined as interventional cardiologists practicing with other cardiologists who are like themselves, in this case, by access-site preference. Previous research in dissemination and social influence in health care describes the importance of informal social networks as it pertains to the spread of diseases and health behaviors;<sup>32,33</sup> we posit this dynamic also pertains to physician decision-making in interventional cardiology and serves as a mechanism of diffusion of innovative treatment. We have yet to understand how cardiologists may influence each other, or how, for example, an early career stage peer (Aim 2) may create tension to change to new procedures, or conversely be influenced to turn away from new procedures by more senior peers. Our work will fill some of the gap in understanding cardiologist-peer influence. Findings from this study will help us understand factors on which we can potentially intervene to ensure physician staff who are adopting evidenced-based innovative care are equally distributed across VA hospitals. Specifically, this will help justify whether incentives for greater diversification of staff with expertise or additional training in innovative coronary procedures are needed. This will maintain VA's mission to continue delivering high-quality and innovative care to its patients while furthering our understanding of physician populations within VA and inform efforts to understand physician populations outside of the VA. Clinical practice patterns in cardiology will have cascading implications for quality of care, patient outcomes, and health care costs given the volume of current and future patients requiring cardiac interventions and care in and outside of VHA.

My research aimed to quantitatively examine individual and interpersonal factors related to a physician's work environment that may contribute to adoption of innovative procedures in a health system. Robust clinical data available at VA allowed us to study provider-level factors associated with practice patterns that reflect physician decisions to adopt innovative coronary procedures. This study examined the source of practice pattern differences across VA (Aim 1), individual (Aim 2), and interpersonal (Aim 3) factors hypothesized to be associated with cardiologist social climate and determinants of physician decision making at VHA:

**Aim 1: Determine the variation in adoption of 4 innovative coronary intervention procedures attributable to region, hospital, operator, and patient.**

**Aim 2: Assess if early-stage career interventional cardiologists (i.e., operators practicing for less than 5 years since clinical fellowship training) are more likely to perform innovative procedures.**

**Aim 3: Determine how the arrival of a radial-dominant operator affects the use of the trans-radial approach among existing operators in a hospital.**

Findings from this research are expected to provide evidence to support potential strategies for improved implementation of innovative evidence-based care, and ultimately, a medical culture that can integrate new ideas and dynamics to achieve sustained change. What follows is a collection of three research manuscripts that sought to answer the research questions presented.

## CHAPTER 1: Practice Pattern Variation in Adoption Of New And Evolving Catheterization Laboratory Procedures (AIM 1)

### ABSTRACT

**Objective.** Assess factors contributing to variation in use of new and evolving diagnostic and intervention procedures in cardiac catheterization laboratories (cath lab).

**Background.** Diagnostic and intervention procedures available to patients have the potential to improve outcomes but are unevenly adopted. Understanding potential drivers of use variability is important in efforts to increase overall procedure use.

**Methods.** Veterans Affairs Clinical Assessment, Reporting, and Tracking (CART) Program data were used to estimate proportion of variation attributable to three levels: hospital, operator, and patient, across four procedures: (a) radial arterial access, (b) intracoronary hemodynamics assessment via fractional flow reserve (FFR) and instantaneous wave-free ratio (iFR), (c) intravascular imaging/optical coherence tomography (IVUS & OCT), and (d) atherectomy for percutaneous coronary intervention (PCI). We used random-effects models with hospital, operator, and patient random effects.

**Results.** Between 2011 and 2018, 445 operators performed procedures on 95,391 PCI patients across 73 hospitals. Rates of all four procedures increased over this time. 24.45% of variability in use of *radial access* was attributable to the hospital, 53.04% to the operator, and 57.83% to patient-level characteristics. 19.72% of variability in use of *FFR/iFR* was attributed to hospital, 25.88% to operator, and 29.85% to patient. 9.06% of variability in *intravascular imaging* use was driven by hospital, 43.92% by operator, and 21.20% by patient. Lastly, 20.16% of variability in use of *atherectomy* was attributed to the hospital, 34.63% to operator, and 57.50% to patient. Overlap between levels generated cumulative variability estimates greater than 100%.

**Conclusions.** Patients and operators contribute more to variability in procedure use than hospitals. New understanding of potential drivers could guide efforts increase or change use of procedures.

### INTRODUCTION

The field of cardiology has continued to see advances in medications, therapies, and medical imaging in the last decade. Despite this technological progress, varied application of specialized knowledge and skills persists.<sup>34</sup> Medical practice variations have been documented across US regions, hospitals, and physicians since the 1980s<sup>35-37</sup> and suggest factors related to a physician's practice style, or application of specialized knowledge and skills, may be a source of variation.<sup>38,39</sup> Clinical decisions by a physician may drive adoption, as can organizational policies or trends in a particular geographic region or a combination of these factors. Patient-

level characteristics can also drive decisions. For example, a patient with small arteries or occurrence of radial spasms can lead a provider to abandon the use of radial arterial access prior to or during a procedure.<sup>40</sup> Innovation adoption in general—the action or fact of choosing to use something that is new or perceived as new—and in healthcare is often unpredictable, and its drivers remain elusive. To our knowledge, potential drivers of this varied application have yet to be assessed in the context of interventional cardiology over time and in a defined population of hospitals, providers, and patients belonging to a national integrated healthcare system.

Understanding where we observe variation is an essential first step in defining what may cause it.

The Veterans Health Administration (VHA) is a national integrated healthcare system with a Clinical Assessment, Reporting, and Tracking (CART) Program that captures procedure information for each cardiac catheterization laboratory (cath lab) across the country. In this work, we assessed four cardiac catheterization laboratory (cath lab) procedures with varying levels of accumulating evidence and support that are readily captured in CART. This includes use of an updated procedure recommendation: (a) radial artery access (TRA); two diagnostic methodologies: (b) intracoronary hemodynamics assessment via fractional flow reserve (FFR) and instantaneous wave-free ratio (iFR), (c) intravascular imaging via ultrasound (IVUS)/optical coherence tomography (OCT), and a less-used interventional procedure: (d) atherectomy. *Trans-radial access* is the primary access method during coronary intervention procedures in many countries.<sup>19,20</sup> Scientific evidence supporting its benefits has existed for over 20 years and a 2015 report officially recommended it as the default access method.<sup>21</sup> It is an innovation to the extent that there are still many practitioners and organizations that have not yet been persuaded to adopt it. *Atherectomy*, or rotational atherectomy as it is formally called, is an approach that has existed since 1988;<sup>22</sup> however, unlike TRA, the evidence and scientific support for its clinical benefits is still being amassed. There is promising research suggesting it facilitates success rates of complex PCI procedures<sup>23</sup>, but the impact on patient

outcomes, especially those with stent placement is not yet conclusive.<sup>24</sup> Use of *intravascular ultrasound (IVUS)* and its analog *optical coherence tomography (OCT)* guidance for arterial access (radial or femoral) has been conclusively shown to improve patient outcomes.<sup>25,26</sup> Despite this, it remains underused in many cath labs,<sup>24</sup> suggesting it has yet to be fully adopted by providers. Intracoronary hemodynamics assessments via *fractional flow reserve (FFR)* and *instantaneous wave-free ratio* is another imaging technique that, like IVUS, adds anatomic and physiologic data concerning the state of lesions in a patient, to help a clinician decide about intervening on potentially complex lesions. Long-term data has also shown that FFR-guided decision-making helps reduce unnecessary interventions for patients and overall improved outcomes<sup>27</sup> making FFR, like IVUS, a well-supported evidence-based practice.

Given diseases of the heart remain the leading cause of death in the United States (US)<sup>41–43</sup> and its sky-high care-related costs are expected to rise over the next 15 years<sup>42,44,45</sup>, potential drivers of disparate technology use are important to understand inasmuch that disparate use generates inconsistent health outcomes and expensive, suboptimal quality of care.<sup>19,20,24–26,46</sup> Furthermore, the best way to promote new and evolving technologies in the cardiac catheterization lab (cath lab), and among physicians in general, is unclear. To explore possible factors causing differences in use, or adoption, this study evaluates three potential drivers—hospital, operator, patient—to determine which might contribute most to use variability overall. Specifically, we quantify variation attributable to the three levels across four procedure types across Veterans Health Administration (VA) hospitals using data from their Clinical Assessment, Reporting, and Tracking (CART) Program.

## **METHODS**

We used data from the Veterans Health Administration (VA) Clinical Assessment Reporting and Tracking Program for cardiac catheterization laboratories (CART). CART is a data repository for clinical care communications and supports national reporting and quality improvement initiatives

across VA hospitals. Operators enter procedures and patient characteristics into the CART system, such as pre-procedure patient risk and indications as well as post-procedure outcomes for all coronary procedures performed in VA hospitals. The data entry elements are derived from the National Cardiovascular Data Registry (NCDR) and considered accurate and valid per ongoing independent assessment.<sup>47</sup>

Through CART, we identified all percutaneous coronary interventions (PCIs) performed 2011-2018 in VA hospitals across the US. This retrospective longitudinal analysis was based on a subpopulation of 450 operators who reported performing greater than or equal to 10 PCIs in any on year. These 450 operators collectively performed 95,391 interventions at 73 VA hospitals across the US. We performed complete case analysis, excluding observations with missing data. Data analysis was performed between June 2020 and March 2021. The University of Washington and VA Internal Review Boards reviewed and determined the present study to be exempt from the need for oversight.

### ***Measures***

Primary Outcome. Procedure-use indication captured in CART as a binary (yes/no) outcome for each of the 4 procedures, was the outcome of interest. The goal was to quantify how much of the variability in procedure use (yes vs. no), for each procedure, use was coming from hospital, operator, or patient level.

Primary Predictors. We assessed the following variables as potential drivers of practice pattern variation: (1) *hospital*, (2) *operator* (i.e., physician), and (3) *patient*. Each of these are uniquely identified in the data set. *Variance* is defined as a numerical value that indicates how widely units (e.g., individuals) in a group vary, and characterizes this difference from the group mean. Variance attributable to each of the primary predictors is our primary outcome in this

investigation. We assessed the probability of procedure use: *radial arterial access*, intracoronary hemodynamics (*FFR/iFR*), intracoronary imaging (*IVUS & OCT*) and *atherectomy*. These techniques were selected a priori due to their availability in CART and for being likely to vary in use due to hospital, physician, and patient-level factors. Use of radial access, FFR/iFR, IVUS & OCT, and atherectomy were identified through CART indicator variables for each procedure; indicator variables are derived from ICD-9 and ICD-10 procedure codes.

We used *presence of cardiac surgery*, an indication that the hospital could perform more complex procedures due to availability of cardiothoracic surgery backup, as a hospital-level covariate. *Operator age and sex* were included as operator-level covariates. Patient-level covariates were assessed based on chart review and included sociodemographic characteristics such as patient *age, sex, race, and ethnicity*, indicators of cardiovascular health such as patient body mass index (*BMI; normal, obese, overweight, or underweight*), receipt of *prior PCI*, and receipt of *prior coronary artery bypass graft surgery (CABG)*; additional indicators of health included presence/absence of *acute coronary syndrome (ACS)*, *prior cardiogenic shock*, *cerebrovascular disease (CVD)*, *chronic kidney disease (CKD)*, *diabetes*, *congestive heart failure (CHF)*, *hyperlipidemia*, *hypertension*, *prior myocardial infarction (MI)*, and *peripheral artery/vascular disease (PAD)*. *Procedure priority*, a variable indicating severity of disease and thus importance of the case: elective, elective staged, emergent, salvage, or urgent was also included at the patient level. Covariates at all levels—hospital, operator, and patient—were selected a priori based on their possible explanatory relationship with procedure use.

### ***Statistical Analyses***

We calculated proportions for all hospital, physician, and patient characteristics. We also calculated proportions of procedure use counts over time for each procedure. We fit multilevel random-effects models to derive probability of procedure use, account for in-hospital and by-physician clustering, and to quantify the variance attributable to and within each level in our analysis: hospital (level 3), physician (level 2), and patient (level 1). Analyses were performed on a procedure level. Log-link binomial generalized linear mixed models (GLMM) with robust variance estimators were used to model procedure use as a function of the covariates for each outcome. All models contained time as a fixed effect. We included random effects for hospital, physician, and patient in all the procedure-specific models. In total, there were 4 separate models with (1) *radial access*, (2) *FFR/iFR*, (3) *IVUS/OCT*, and (4) *atherectomy* use as the outcome (Table 3). Variance estimates provided by the models were used to calculate the intraclass correlation coefficient (ICC), or variability attributed to the random effect (i.e., cluster). Total variability as the sum of each—hospital, operator, and patient—variance component was expected to be either below or above 100%; a sum of 100% would indicate that we captured all variability perfectly. Sum of variance above 100% would indicate overlap between variance components in our models and sum below 100% would indicate that we had not incorporated enough of them. We encountered convergence issues when fitting the multilevel random effects models, likely due to overparameterization. To address these issues, we removed hospital, physician, and patient-level covariates; time remained a fixed effect. All analyses were conducted using STATA 16.

## RESULTS

The patients who received the 95,391 procedures were predominantly male (98.45%), non-Hispanic (94.62%), white (84.48%), belonging to BMI categories of overweight (34.95%) and

obese (47.79%), with indications for hyperlipidemia (93.12%), hypertension (92.73%), and prior PCI (52.98%), compared to other patients in the sample. Procedures tended to be elective (57.77%) or urgent (28.63%) and take place in hospitals with presence of cardiac surgery (68.99%) (Table 1). Overall use between 2011 and 2018 of *radial access* was 35.45%, *FFR/iFR* use was 7.29%, *IVUS & OCT* was 4.32% and *atherectomy* was 1.35%. Procedure use increased each subsequent year, with *radial access*, *IVUS & OCT*, and *atherectomy* showing the largest increase in proportion over time. *Radial access* or *FFR/iFR* use was notably low in patients with prior CABG, 17.64% and 18.95%, respectively.

Most variability in procedure adoption was observed at the patient level, except for *radial access* and *IVUS & OCT*, where a large proportion of variability was observed at the physician level. 57.83% of variability in adoption of *radial access* was driven by the patient, 53.04% by physician, and 24.45% by the hospital. 19.72% of variability in adoption of *FFR* was attributed to hospital, 25.88% to physician, and 29.85% to patient. 9.06% of variability in *IVUS/OCT* use was driven by hospital, 43.92% by operator, and 21.20% by patient. Lastly, 20.16% of variability in adoption of *atherectomy* was attributed to the hospital, 34.63% to operator, and 57.50% to patient. Hospital contributed least across all procedures. (Table 2).

## **DISCUSSION**

This study set out to quantify how much of the variability in procedure use was attributable to the hospital, operator, or patient level in VA healthcare system. The best way to promote new and evolving technologies in the cath lab, and among physicians in general, is unclear. Potential drivers PCI innovation adoption had yet to be assessed in the context of interventional cardiology, but generally, and perhaps especially, in a defined population of hospitals, providers, and patients over time. In this descriptive analysis of potential care-level factors affecting

innovation-adoption, we observed that *operators* could potentially affect the use of PCI innovations. Clinical decisions are expected to be primarily motivated by patient characteristics;<sup>48,49</sup> however, given the observed operator-level contributions, further exploration into whether provider personal preferences play a more meaningful role, appears warranted. For example, preference-motivated choices could amount to detectable differences in a system's overall adoption of new procedures. Our results also suggest that there are potentially more levels, or factors, contributing to these differences that we have not yet accounted for.<sup>30</sup> One example of this could be operators who also hold appointments at different healthcare systems (e.g., university medical centers); the other system's enforced practices might have an impact on an operator's choices at VA that we cannot measure. These findings also corroborate the premise that all levels of care play some role, and that there may be overlap between them. For example, we observed most variability contribution from the patient level, however this might be due to patient advocacy instead of their current clinical health indicators, which might be entirely dependent on the hospital's communication with the patient on new practices—a hospital-level factor overlapping a patient-level one.

There are several limitations to our work. The PCI innovations we evaluated have varying levels of support. Some are evidence-based, like vascular access site recommendations.<sup>19-21</sup> But there are some for which the evidence base is still being developed and/or might only be indicated for a small subset of patients, and only in cases of severe disease (e.g., atherectomies).<sup>24-26</sup> In line with this is the observation generated by our work that the type of procedure appeared to modify the level contributing most to overall procedure-use variability. Lastly, we did not have measures for additional hospital or operator-level factors such as hospital

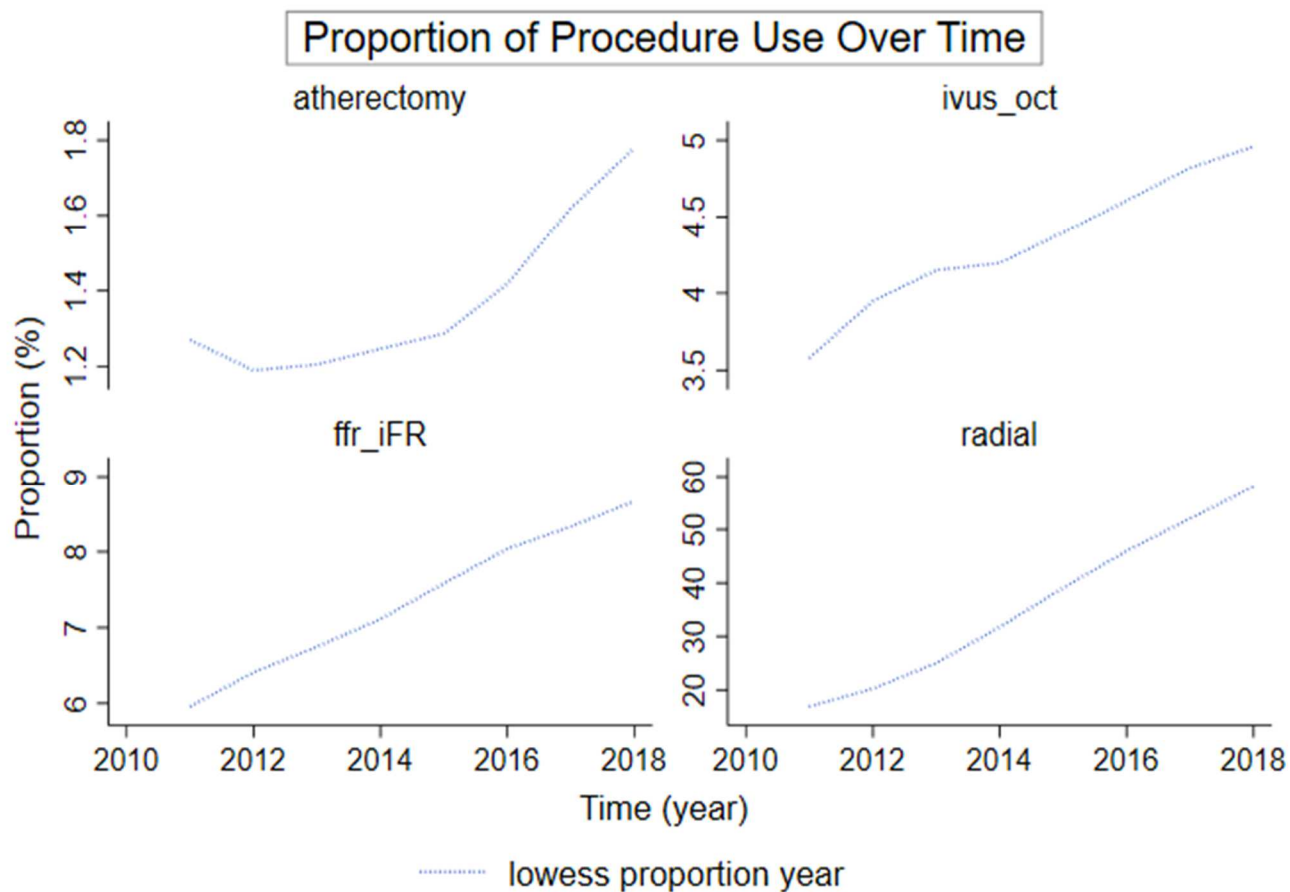
leadership support or operator decision making,<sup>15,50</sup> that might meaningfully contribute to innovation adoption overall.

With respect to our analysis, achieving efficient and complete model convergence proved challenging and required modifications. One of these modifications required the removal of covariates at all levels of our analysis—hospital, operator, patient. Without adjusting for these additional, potential explanatory factors, our results may over or underestimate the relationship between our three levels and overall variance. Furthermore, there are limitations to the calculations made by our statistical programs. For example, within-cluster variance cannot be calculated forthright in multi-level models with binary outcomes. To facilitate technical convergence of statistical models, we also applied a specific type of estimator, or mathematical tool to help approximate calculation of our results. In this analysis, we used one such estimator called the “Laplacian estimator”, known for its imprecise estimation of the random effect, which underpins our variance component calculations.

Further analysis of relative advantage, cost, and other characteristics pertaining to the evolving PCI technologies examined was beyond the scope of this study. The illustrated differences in adoption rate over time by type of innovation indicates that some of what drives adoption is likely unrelated to innovation characteristics; more research is needed to understand the interaction between specific innovation characteristics, such as cost, and each of the levels contributing to uneven adoption, including the ones we studied here and others we were unable to study. Cost of equipment necessary to perform an atherectomy, for example, could be important to hospitals, but irrelevant to providers or patients.

## **CONCLUSION**

Understanding where we observe variation is a foundational step in defining what may cause it. Healthcare system efforts to promote new procedures and practices can be more effectively tailored through improved understanding of what care-delivery level contributes most to disparate application of novel skills and knowledge.



Note: Values based on CATH & PCI

Figure 2: Proportion of Procedure Use Over Time in VA Hospitals\*

\*We applied a scatter plot smoothing tool called a locally weighted scatterplot smoothing (LOWESS) curve, which draws a curve through the plot as an aid to visualize trends, where it would otherwise be challenging to see a best fitting curve.

Table 1. Patient Characteristics Across Procedure Types 2011-2018

<b>TABLE 1. Patient Characteristics Across Procedure Types 2011-2018 (N=95,391)</b>				
<i>Procedure Type</i>	<i>Radial Access</i>	<i>FFR/iFR</i>	<i>IVUS &amp; OCT</i>	<i>Atherectomy</i>
<b>Procedure Receipt, n (%)</b>	<b>Yes 29,218 (30.63)</b>	<b>Yes 9,304 (9.75)</b>	<b>Yes 11,302 (11.85)</b>	<b>Yes 4,811 (5.04)</b>
<b>Sex, n (%)</b>				
<i>Female</i>	493 (1.69)	172 (1.85)	185 (1.64)	57 (1.18)
<b>Race</b>				
<i>American Indian or Alaskan Native</i>	246(0.84)	79 (0.85)	109 (0.96)	50 (1.04)
<i>Asian</i>	268 (0.92)	101 (1.09)	141 (1.25)	34 (0.71)
<i>Black or African American</i>	4,759 (16.29)	1,284 (13.80)	1,603 (14.18)	651 (13.53)
<i>Native Hawaiian or Other Pacific Islander</i>	171 (0.59)	35 (0.38)	65 (0.58)	25 (0.52)
<i>White</i>	23,774 (81.73)	7,805 (83.89)	9,384 (83.03)	4,051 (84.20)
<b>Ethnicity</b>				
<i>Hispanic</i>	1,304 (4.46)	461 (4.95)	652 (5.77)	85,977 (94.92)
<i>Non-Hispanic</i>	27,914 (95.54)	8,843 (95.05)	10,650 (94.23)	4,547 (94.51)
<b>Body Mass Index (BMI, kg/m<sup>2</sup>)</b>				
<i>Normal (18.5-24.9)</i>	4,228 (14.47)	1,274 (13.69)	1,782 (15.77)	887 (18.44)
<i>Underweight (&lt;18.5)</i>	163 (0.56)	53 (0.57)	76 (0.67)	36 (0.75)
<i>Overweight (25.0-29.9)</i>	9,736 (33.32)	3,154 (33.90)	3,993 (35.33)	1,678 (34.88)
<i>Obese (30.0-34.9)</i>	14,765 (50.53)	4,715 (50.68)	5,358 (47.41)	2,171 (45.13)
<i>Missing</i>	326 (1.12)	108 (1.16)	93 (0.82)	39 (0.81)
<b>Prior Percutaneous Coronary Intervention (PCI)</b>				
<i>Yes</i>	13,987 (47.87)	4,952 (53.22)	6,181 (54.69)	2,570 (53.42)
<b>Prior Coronary Artery Bypass Graft Surgery (CABG)</b>				
<i>Yes</i>	5,154 (17.64)	1,763 (18.95)	2,886 (25.54)	1,433 (29.79)
<b>Acute Coronary Syndrome (ACS)</b>				
<i>Yes</i>	270 (0.92)	109 (1.17)	119 (1.05)	21 (0.44)
<b>Prior Cardiogenic Shock</b>				
<i>Yes</i>	422 (1.44)	113 (1.21)	217 (1.92)	92 (1.91)
<b>Cerebrovascular disease (CVD)</b>				
<i>Yes</i>	6,002 (20.54)	2,008 (21.58)	2,523 (22.32)	1,343 (27.92)
<b>Chronic kidney disease (CKD)</b>				
<i>Yes</i>	6,747 (23.09)	2,054 (22.08)	2,839 (25.12)	1,495 (31.07)
<b>Diabetes</b>				
<i>Yes</i>	15,277 (52.29)	4,942 (53.12)	5,872 (51.96)	2,878 (59.82)
<b>Congestive Heart Failure</b>				
<i>Yes</i>	8,489 (29.05)	2,823 (30.34)	3,912 (34.16)	2,025 (42.09)
<b>Hyperlipidemia</b>				
<i>Yes</i>	26,849 (91.89)	8,694 (93.44)	10,449 (92.45)	4,518 (93.91)
<b>Hypertension</b>				

<i>Yes</i>	27, 057 (92.60)	8, 688 (93.38)	10, 434 (92.32)	4, 596 (95.53)
<b>Peripheral Artery Disease</b>				
<i>Yes</i>	7, 396 (25.31)	2, 239 (24.06)	3, 068 (27.15)	1, 795 (37.31)
<b>Prior MI</b>				
<i>Yes</i>	12, 000 (41.07)	3, 780 (40.63)	5,182 (45.85)	2, 271 (47.20)
<b>Procedure Priority</b>				
<i>Elective-Staged</i>	1, 542 (5.28)	525 (5.64)	1, 058 (9.36)	721 (14.99)
<i>Elective</i>	17, 741 (60.72)	6, 589 (70.82)	6, 400 (56.63)	2, 979 (61.92)
<i>Emergent</i>	1, 187 (4.06)	55 (0.59)	578 (5.11)	44 (0.91)
<i>Urgent</i>	8, 394 (28.73)	2, 017 (21.68)	3, 159 (27.95)	1, 020 (21.20)
<i>Salvage</i>	23 (0.08)	2 (0.02)	18 (0.16)	6 (0.12)
<i>Missing</i>	331 (1.13)	116 (1.25)	89 (0.79)	41 (0.85)
<b>Prior Treatment</b>				
<i>Yes</i>	2, 794 (9.56)	774 (8.32)	1, 541 (13.63)	368 (7.65)
<b>Left Main</b>				
<i>Yes</i>	484 (1.66)	218 (2.34)	813 (7.19)	353 (7.34)
<b>Bifurcation</b>				
<i>Yes</i>	2, 012 (6.89)	547 (5.88)	881 (7.80)	385 (8.00)
<b>Graft</b>				
<i>Yes</i>	1, 047 (3.58)	214 (2.30)	619 (5.48)	60 (1.25)
<b>Chronic Total Occlusion (CTO)</b>				
<i>Yes</i>	1, 131 (3.87)	263 (2.83)	567 (5.02)	358 (7.44)

Table 2. Procedure Use by Cath &amp; PCI 2011-2018

PROCEDURE USE n(%)	CATH LAB SESSION TYPE		Total
	CATH	PCI	
<b>1. Radial access</b>			
No	162,233 (62.76)	66,173 (69.37)	228,406 (64.54)
Yes	96,270 (37.24)	29,218 (30.63)	125,488 (35.46)
<b>2. FFR/iFR</b>			
No	241,910 (93.58)	86,087 (90.25)	327,997(92.68)
Yes	16,593 (6.42)	9,304 (9.75)	25,897 (7.32)
<b>3. IVUS &amp; OCT</b>			
No	254,490 (98.45)	84,089(88.15)	338,579(95.67)
Yes	4,013 (1.55)	11,302 (11.85)	15,315 (4.33)
<b>4. Atherectomy</b>			
No	258,503 (100)	90,580 (94.96)	349,083 (98.64)
Yes	0 (0)	4,811 (5.04)	4,811 (1.36)
Total	<b>258,503 (73.05)</b>	<b>95,391(26.95)</b>	<b>353,894 (100)</b>

\*Based on procedure documentation at time of delivery in CART (i.e., chart review)

Table 3. Percent of Total Variance Attributable to Hospital, Physician, or Patient

TABLE 3. Percent of Total Variance\* Attributable to Hospital, Physician, or Patient

PROCEDURE	LEVEL OF CARE		
	Hospital	Physician	Patient
1. Radial Access	24.45%	53.04%	57.83%
2. FFR	19.72%	25.88%	29.85%
3. IVUS/OCT	9.06%	43.92%	21.20%
4. Atherectomy	20.16%	34.63%	57.50%

\*Variance calculated as intra-class correlation (ICC)<sup>+</sup> and reported as percentage.

$$+ ICC = \frac{\text{var}(u_{0j})}{\text{var}(u_{0j}) + \left(\frac{\pi^2}{2}\right)}$$

## **CHAPTER 2: Career Stage and Adoption of Cath Lab Procedures Over Time: An Observational Study Among Operators in VA Hospitals (AIM 2)**

### **ABSTRACT**

In this study we examined whether cardiologist career stage (i.e., time elapsed since clinical fellowship training) is associated with delivery of 4 coronary intervention procedures in the US Veterans Affairs Healthcare System (VA). Data from the Veterans Affairs Clinical Assessment, Reporting, and Tracking Program (2011-2018) were used to estimate the association between career stage and use of (a) radial access (b) intravascular imaging (intravascular ultrasound and optical coherence tomography), (c) fractional flow reserve (FFR/iFR), and (d) atherectomy for percutaneous coronary intervention (PCI), with both unadjusted and adjusted logistic mixed-effects modeling. Among 296,076 cardiac procedures performed by 294 interventional cardiologists (operators) at 69 hospitals across 18 regions, we found that career stage was associated with likelihood of using 4 practices—radial access, FFR/iFR, intravascular imaging, atherectomy—across CATHs and PCIs overall, after adjusting for patient factors. Mid-career operators, or those within 6-10 years from formal training, were more likely than early-career peers to use these practices. On the other hand, operators within 11 years from formal training or higher (late-career) were less likely than early-career peers to use the same procedures. However, both late- and mid-career operators were more likely to perform atherectomy than early-career operators. These findings provide preliminary support for further investigation of the link between career stage and use of varying cath lab procedures. Future research is needed to better understand the specific mechanisms by which career stage might influence procedure adoption in the cardiac catheterization laboratory.

### **INTRODUCTION**

Cardiovascular medicine has seen many advances in therapies and medical imaging over the last decade, and emerging technologies are expected to play more prominent roles in current and future clinical practice, especially in the cardiac catheterization laboratory.<sup>41,51,52</sup> There is evidence that some procedures, such as imaging-guided and transradial access percutaneous coronary intervention (PCI), are associated with improved clinical effectiveness and patient outcomes.<sup>46,53–55</sup> Nevertheless, adoption of these procedures varies.<sup>16,45,56–58</sup> This variation in adoption does not necessarily follow patient clinical presentation and needs; relatively little is known about how these procedures are adopted in practice. It is possible that operators may establish practice patterns during training (e.g., fellowship) that persist over the course of their careers and present a way that these practices can be spread and established.<sup>8,30,59,60</sup> In this study, we assessed the relationship between cardiologist career stage (i.e., time elapsed since training), and use of 4 practices across diagnostic angiograms (CATHs) and PCIs. For CATHs, we

assessed: (1) transradial vascular access and (2) fractional flow reserve (FFR/iFR), and for PCIs we assessed (1) transradial vascular access, (2) intravascular imaging (intravascular ultrasound and optical coherence tomography), and (3) atherectomy. These practices represent differing levels of published evidence and professional consensus for their use; we posited that early-career operators would be more likely to use these procedures in practice given they experience less elapsed time from training where these practice norms may be established.

## **METHODS**

We used data from the Department of Veterans Affairs (VA) Clinical Assessment Reporting and Tracking (CART) Program to evaluate all VA patients (N=296,076) who underwent CATH or PCI (excluding coronary angiography and PCI performed during the same session) between January 2011 and December 2018. We supplemented CART data with publicly available training information, specifically *year of interventional cardiology certificate* for each PCI operator in the sample (n=294), based on their national provider identifier. We excluded providers (n=156) without a recorded certificate date from our sample. We focused our analysis on patients who received procedures/practices measured in CART cross CATH and PCI sessions. For CATHs, we assessed: (1) transradial vascular access or (2) FFR/iFR, and for PCIs we assessed (1) transradial vascular access, (2) intravascular imaging, and (3) atherectomy.

The dependent variable was patient receipt of procedure. This was defined by yes/no indication of use in CART data fields, as recorded by operators during a procedure session. The independent variable of interest was operator career stage. PCI operators were categorized as being in early, middle, or late-stage career. An early-career PCI operator was defined as being within 5 years of training, a commonly accepted threshold of experience in the field.<sup>61</sup> We constructed a variable indicating whether providers in 2018 were (A) early career (less than, and inclusive of, 5 years of training), (B) mid-career (within 6-10 years of training), or (C) late career (greater than and inclusive of 11 years from training). This variable was based on elapsed time between 2018 and when the training certificate was recorded. Patient-level covariates included: indication of prior percutaneous PCI, coronary artery bypass graft surgery, acute coronary syndrome, prior cardiogenic shock, cardiovascular disease, chronic kidney disease, diabetes

mellitus, congestive heart failure, hyperlipidemia, hypertension, peripheral artery disease, prior myocardial infarction, age, gender, and ethnicity.

Proportions for all patient-level covariates were calculated for the overall sample, stratified by operator career stage. We used logistic mixed-effects models to estimate the association between patient receipt of procedure and interventional cardiologist career stage. Our adjusted models included time and patient-level covariates as fixed effects, and hospital as a random effect, to evaluate whether accounting for these attenuated or strengthened the results in the unadjusted models. All analyses were conducted using STATA 16.

## RESULTS

CATH patients across all 3 operator career stages were predominantly white, male, non-Hispanic, and have had prior PCI, with hyperlipidemia and hypertension. Late-career operators cared for most CATH patients in the sample (n=114,354). PCI patients across all three operator career stages were also more likely to be white, male, and non-Hispanic with hyperlipidemia and hypertension. They were also more likely to have experienced prior treatment and acute coronary syndrome. Late-career operators also cared for most PCI patients in the sample (n=52,385) and were slightly more likely to care for patients with acute coronary syndrome (Tables 4 and 5).

The results for all unadjusted models are presented in Tables 6 and 7. In adjusted models for CATHs (Table 3), mid-career operators were more likely than their early-career peers to perform radial-artery access (odds ratio =1.19, 95% odds ratio: 1.15-1.23) or FFR/iFR during procedures (odds ratio=1.10, 95% confidence interval: 1.02-1.14). Late-career operators were less likely than early-career operators to perform radial-artery access (odds ratio =0.80, 95% confidence interval: 0.78-0.82), and were no more or less likely to perform FFR/iFR than their early-career peers (odds ratio =1.00, 95% confidence interval: 0.96-1.05).

In adjusted models for PCIs (Table 4), mid-career operators were more likely to perform radial-artery access (odds ratio =1.07, 95% confidence interval: 1.02-1.14), intravascular imaging (odds ratio =1.06, 95% confidence interval: 0.99-1.14), and atherectomy (odds ratio=1.31, 95% confidence interval:

1.16-1.50) than early-career peers. Late-career operators were less likely to perform radial-artery access and intravascular imaging than early-career peers (odds ratio =0.72, 95% confidence interval: 0.70-0.76), odds ratio =0.57, 95% confidence interval: 0.54-0.60, respectively). Late-career operators were more likely to perform atherectomy than early-career operators (odds ratio =1.13, 95% confidence interval: 1.02-1.25).

## **DISCUSSION**

We found that career stage was associated with likelihood of using 4 practices—radial access, FFR/iFR, intravascular imaging, atherectomy—across CATHs and PCIs overall, after adjusting for patient factors. The higher likelihood of use among mid-career operators was unexpected; we had posited that all later career stages would be less likely than early-career operators to adopt procedures. We learned mid-career operators, or those 6-10 years removed from formal training, were more likely than early-career peers to use these practices. On the other hand, operators 11 years removed from formal training or higher (late-career) were less likely than early-career peers to use the same procedures. The one exception to our findings is in use of atherectomy, which both late- and mid-career operators were more likely to perform than early-career operators. Again, this stands in contrast to our initial hypothesis that early-career operators would be more likely to adopt procedures than mid and late career peers.

Our findings have several potential implications, and raise a range of questions for future research. Our results suggest that there are meaningful differences in cath lab procedure use based on career stage, in general. This highlights the potential importance of training, but it also highlights other aspects of experience that may also play a role. This raises number of questions for future research, namely if there is a distinct or synergistic effect between what you might be exposed to during training and how many cases, or instances of practice, operators have. There are other speculations to be made about what other operator-specific characteristics (e.g., confidence, seniority) might underpin the mechanisms by which mid-career operators become more likely to adopt procedures given the persistent pattern we observe even after adjusting for patient-level factors, and clustering on the hospital-level.

Our findings provide preliminary support for further investigation of the link between career stage and use of varying technologies during procedures. Our results suggest that there are meaningful differences in procedure use based on career stage, in general. This descriptive analysis sought to explore the potential relationship between operator career tenure and use of practices with varying levels of support and evidence. This ambiguity of clinical evidence, at least initially, is a hallmark of emerging novel technologies. Similarly, there is typically marked variation in how procedures or novelties in procedure management, are adopted—including the procedure itself and/or its accompanying gadgets. As emerging technologies play more prominent roles in current and future practice, we thought it important to understand potential variables implicated in their ultimate use. Training programs such as fellowship or continuing medical education, are potential ways that novel technologies are disseminated. It is also possible that operators may establish practice patterns during training that persist over the course of their careers, thus making career stage—a measure of time in practice and training era—a reasonable predictor of technology use. Prior studies have demonstrated that innovative or evidence-based care is adopted unevenly across the country,<sup>6,13,16,17</sup> a pattern reflected in the VA healthcare system and interventional cardiology,<sup>11,18–21</sup> Our findings support other studies that have suggested clinical decisions are influenced by factors unrelated to patient characteristics and that there may be a sphere of influence pertaining exclusively to the provider (e.g., age, career stage, and risk tolerance).<sup>14,15,22</sup>

Our work is limited in several ways. Perhaps most notable is our crude definition of career stage. We computed career stage as difference between 2018, the last year of our data set, and the recorded year of receipt of training certificate. The distance from recorded certification is not a perfect measure of experience. There may have been delays between training and the practice patterns we observed in our data that were not specified or possible to capture. For example, an operator could be fellowship-trained in vascular-imaging but might not have taken an attending position at a lab that had the requisite equipment until several years later. Further, other potentially changing characteristics without relationship to career stage, such as risk tolerance and interest in enterprising, could play a significant role in the how

decisions are made in the face of emerging cath lab procedures. Another limitation is our inability to measure the operator's *perceived* career stage. It is possible that someone 15-years removed from training (late-career by our metric) might perceive themselves instead as mid-career with respect to a specific procedure and its accompanying tools, and thus behave less like the late-career operator we would expect based on our findings. Nonetheless, our experimental inquiry provides insight into some aspect of the relationship between training and practice decisions over time, within labs belonging an integrated healthcare system providing service to 296, 076 patients across the country. Our results are important because they support the theory that adopting new practices in cardiology is influenced to some degree by physician-level characteristics such as career stage.

Future research is needed to better understand the specific mechanisms by which career stage might influence clinical decisions. Though we adjusted for time in our models, it is possible that there are other time-dependent factors, such as hospital policies, that might play a bigger role than career stage. Ultimately, our finding that procedure use varies by career stage begs further inquiry into what might be causing the observed association and what might be done to ensure that its influence in determining patient receipt of procedures does not negatively impact quality of care and patient outcomes.

Table 4. Sociodemographic and medical history characteristics of patients receiving cardiac catheterization by operator career-stage designation

<b>Characteristic</b>	<b>Early-career (n=30,553)</b>	<b>Mid-career (n=27,381)</b>	<b>Late-career (n=114,354)</b>
<b>Age (Years)</b>			
Mean (standard deviation)	66.91	66.47	66.25
IQR	10	9.9	10.1
<b>Women</b>	2.83	2.87	2.56
<b>Race (%)</b>			
American Indian or Alaskan Native	0.67	0.88	0.89
Asian	1.11	0.94	0.93
Black or African American	14.54	17.39	18.17
Native Hawaiian or Other Pacific Islander	0.41	0.62	0.58
White	83.27	80.17	79.43
<b>Hispanic ethnicity (%)</b>	3.75	3.56	4.99
<b>Prior percutaneous coronary intervention (%)</b>	73.48	67.63	64.61
<b>Prior coronary artery bypass graft surgery (%)</b>	23.06	22.59	23.70
<b>Prior Cardiogenic Shock (%)</b>	1.37	1.79	1.59
<b>Prior cerebrovascular disease (%)</b>	21.25	20.15	20.53
<b>Chronic kidney disease (%)</b>	23.77	22.50	22.79
<b>Diabetes mellitus (%)</b>	51.35	50.13	50.53
<b>Prior congestive heart failure (%)</b>	31.29	28.49	30.47
<b>History of hyperlipidemia (%)</b>	90.80	89.68	89.88
<b>History of hypertension (%)</b>	92.03	90.58	91.09
<b>History of Peripheral arterial disease (%)</b>	24.40	22.21	23.36
<b>Prior myocardial infarction (%)</b>	38.38	36.41	36.96

Table 5 Sociodemographic and medical history characteristics of patients receiving percutaneous coronary intervention by operator career-stage designation

<b>Table 5. Sociodemographic and medical history characteristics of patients receiving percutaneous coronary intervention by operator career-stage designation</b>			
<b>Characteristic</b>	<b>Early-career (n=12,711)</b>	<b>Mid-career (n=11,689)</b>	<b>Late-career (n=52,385)</b>
<b>Age (Years)</b>			
Mean (standard deviation)	66.91	66.47	66.25
IQR	10	9.9	10.1
<b>Women</b>	1.53	1.71	2.56
<b>Race (%)</b>	98.47	98.29	97.44
American Indian or Alaskan Native	0.64	0.76	0.89
Asian	1.09	0.89	0.97
Black or African American	11.87	14.99	14.92
Native Hawaiian or Other Pacific Islander	0.42	0.65	0.55
White	85.99	82.71	82.67
<b>Hispanic ethnicity (%)</b>	4.61	3.86	5.43
<b>Prior percutaneous coronary intervention (%)</b>	52.95	50.57	50.75
<b>Prior coronary artery bypass graft surgery (%)</b>	28.01	22.59	29.15
<b>Prior Cardiogenic Shock (%)</b>	1.79	1.97	2.00
<b>Prior cerebrovascular disease (%)</b>	24.49	22.27	23.15
<b>Chronic kidney disease (%)</b>	26.72	24.54	25.15
<b>Diabetes mellitus (%)</b>	54.83	52.01	53.48
<b>Prior congestive heart failure (%)</b>	33.76	29.56	31.87
<b>History of hyperlipidemia (%)</b>	93.45	91.97	92.91
<b>History of hypertension (%)</b>	93.64	92.10	92.65
<b>History of peripheral arterial disease (%)</b>	29.14	25.10	27.01
<b>Prior myocardial infarction (%)</b>	46.83	43.06	44.64

Table 6. The association of operator career stage and procedure use for cardiac catheterization: results from logistic regression

<b>Career state</b>	<b>Radial artery access (n=)</b>	<b>Fractional flow reserve (n=)</b>
<i>Unadjusted</i>	Odds ratio, 95% confidence interval	Odds ratio, 95% confidence interval
Early (0-5 years)	----	----
Middle (5-10 years)	0.97 (0.94,1.00)	0.97 (0.91,1.02)
Late 11+ years	0.54 (0.53,0.56)	0.91 (0.87,0.95)
<i>Adjusted</i>		
Early (0-5 years)	----	----
Middle (5-10 years)	1.19 (1.15-1.23)	1.10 (1.04-1.24)
Late 11+ years	0.80 (0.78-0.82)	1.00 (0.96-1.05)

Table 7. The association of operator career stage and procedure use for percutaneous coronary intervention: results from logistic regression

<b>Career state</b>	<b>Radial artery access (n=)</b>	<b>Intravascular ultrasound or optical coherence tomography (n=)</b>	<b>Atherectomy (n=)</b>
<i>Unadjusted</i>	Odds ratio, 95% confidence interval	Odds ratio, 95% confidence interval	Odds ratio, 95% confidence interval
Early (0-5 years)	----	----	----
Middle (5-10 years)	0.90 (0.86-0.95)	0.87 (0.81-0.93)	1.00 (0.86-1.13)
Late 11+ years	0.51 (0.49-0.53)	0.50 (0.47-0.53)	0.90 (0.82-0.99)
<i>Adjusted</i>			
Early (0-5 years)	----	----	----
Middle (5-10 years)	1.07 (1.02-1.14)	1.06 (0.99-1.14)	1.31 (1.16-1.50)
Late 11+ years	0.72 (0.70-0.76)	0.57 (0.54-0.60)	1.13 (1.02-1.25)

## CHAPTER 3: Impact of New Radial-First Operator Arrival at Low-Adoption Sites on Use of Transradial Approach: A Retrospective Study of Clinical Data in Interventional Cardiology Across VHA Hospitals (AIM 3)

### ABSTRACT

**Background.** Innovations can diffuse through social networks when potential adopters are exposed to an innovation through other network members. For physicians, peers in the same place of clinical practice represent such a network, and clinical decisions can be influenced by exposure to a new peer that uses an innovative procedure. In interventional cardiology, using radial arterial access (TRA) for coronary procedures still has low rates of adoption despite evidence that it can lead to better patient outcomes than femoral arterial access; more research is needed to understand how to increase adoption rates. In this study, we assessed whether the addition of a new radial-dominant interventional cardiologist (i.e., operator) to a hospital contributes to an increase in radial arterial access procedures by existing interventional cardiologists in the same hospital.

**Methods.** Data from the Veterans Health Administration (VHA) Clinical Assessment Reporting and Tracking (CART-CL) Program (2011-2018) were used to estimate the association between conducting procedures using TRA and belonging to a hospital exposed to a new radial-dominant operator; this was explored for coronary catheterizations (CATH) and interventions (PCI). We used logistic regression and controlled for factors with known associations to radial access selection such as patient indicators of cardiovascular health and demographics.

**Results.** Operators in hospitals exposed to a new radial-dominant operator were 2.63 times more likely to perform cardiac catheterization (CATH) procedures via radial artery than operators in hospitals without exposure (43.24% vs 22.48%, 95% CI:2.58-2.67). Adjustment for both sociodemographic and clinical covariates strengthened the association (OR 3.19; 95% CI:3.13-3.26). Operators in hospitals exposed to a new radial-dominant operator were 2.80 times more likely to perform percutaneous coronary intervention (PCI) procedures via radial artery than cardiologists in hospitals without exposure (37.17% vs 17.44%, 95% CI: 2.71-2.89). Adjustment for covariates strengthened the association (OR 3.25; 95% CI: 3.14-3.37). Descriptive analyses showed new radial-dominant operators tended to join hospitals with higher baseline use of TRA.

**Conclusions.** There was a strong and consistent association between hospital exposure to a new radial-dominant operator and radial access by existing operators. Future efforts to increase adoption of TRA could consider team dynamics in the physician's place of clinical practice and contain efforts to pair innovators with low-adoption sites.

### BACKGROUND

Innovations diffuse through social networks when potential adopters are exposed to the innovation.<sup>62</sup> For physicians, peers in the same place of clinical practice represent such a network. Some evidence suggests physicians are motivated and influenced by more than evidence-based guidelines and recommendations when making clinical decisions.<sup>30</sup> Medical decision-making is defined as the process of formulating diagnoses and treatment plans using facts at hand.<sup>63</sup> Literature examining how physician-peer networks—

the peer-to-peer relationships among physicians—plays into decision making is limited.<sup>5</sup> Clinical decision-making often involves making choices under uncertainty<sup>64</sup> and the exchange of information, or diffusion, about innovation practices from physician-peers may be a highly valued and habituated way of advancing practices. Indeed, physicians tend to maintain horizontal hierarchies,<sup>7</sup> which facilitate this type of exchange.

The demand for cardiology care in the US<sup>41,42</sup> maintains interventional cardiology a field where new procedures and technologies are consistently developed. There are various ways an interventional cardiologist (henceforth operator) can approach these intervention procedures. One such example is deciding how to gain access to a patient's heart vessels (i.e., arterial access). Femoral-artery access has been historically preferred because it offers access to a large vessel and can be technically easier to perform for the operator. Radial-artery access exists as an alternative choice; scientific evidence of its anticipated benefits has existed since 1993 and in 2015, the European Society of Cardiology officially recommended radial over femoral access (i.e., “radial-dominant”) for patients with Acute Coronary Syndrome (ACS).<sup>21</sup> Numerous studies have demonstrated that the radial approach is more comfortable and less dangerous for patients; it is also a less costly approach.<sup>19,20</sup> Despite this, the radial-dominant approach has not been widely adopted in the US; it is employed in only a minority of cases (25-30%), and overall rates of its use are far behind other countries. Despite overwhelming evidence, rates of radial use in the US have increased slowly, albeit progressively. The same pattern is reflected in VHA healthcare system where most TRA use is concentrated in some but not all VA hospitals. In VHA, the leading cause of cardiovascular hospitalization continues to be coronary atherosclerosis<sup>44</sup> and the need for coronary intervention procedures, such as diagnostic angiograms and stent placements, remains steadfast. Previous research demonstrates that innovative coronary intervention procedures are adopted at different rates across VHA hospitals<sup>65</sup>, and remains unclear about what drives this difference. For example, some operators have adopted the radial-dominant strategy, using TRA for greater than eighty percent of their cases. But this TRA-dominant strategy was not widely adopted, suggesting factors beyond evidence-

based guidelines may be contributing to its overall adoption, and especially its use at high rates, more comparable to other countries.

VHA has collected procedural data in cardiology for over a decade, enabling us to quantitatively study factors that may be associated with arterial-access decisions, as reflected in recorded operator practice patterns. The medical tradition of passing down clinical knowledge through practical examples and guidance provides an avenue and setting for potential peer influence during practice. As such, we examined how the arrival of a radial-dominant peer—defined as a *new* operator with a predisposed preference for radial access as the default mode of practice—at a VHA hospital might contribute to TRA adoption by existing operators in the same hospital. We posit that individual-level decisions of existing operators may be modified by the influence of new, innovative physician peers. In this study, we examine whether the presence of peers using TRA influences use of TRA by other physician-peers practicing in hospitals within the VHA healthcare system. Specifically, that an association between new operators and changes in existing operators could suggest a direct impact on what innovations are ultimately used. Our goal was twofold: (I) investigate whether there is an association between radial access use by existing operators and exposure to a new radial-dominant operator, and (II) to explore the possibility that there could be a temporal relationship such that exposure precedes the hypothesized change in radial access use among existing operators.

## **METHODS**

VHA is an integrated healthcare system that provides care to 9.1 million enrollees. This retrospective longitudinal study was a secondary analysis of all VA cardiac catheterization procedures (both diagnostic and coronary interventions) recorded during a patient session in cardiac catheterization laboratories (cath labs) at VA hospitals, occurring January 2011-December 2018. These procedure records were captured through the Clinical Assessment Reporting and Tracking (CART-CL) Program, the national quality and safety program for invasive cardiovascular procedures. Data included patient and procedural information on 327,140 cardiac catheterization procedures, performed by 288 operators at 83 VA hospitals.

The primary outcome is *radial-artery access (TRA)* occurring during either diagnostic (CATH) or intervention catheterizations (PCI). TRA is defined by indication of radial vs femoral artery access during a coronary procedure (CATH or PCI). Radial access was measured dichotomously based on the CART-CL data field asking clinicians what type of access—femoral or radial—was performed on patient during their case. *Existing operators* were defined as operators performing ten cases or more per year at any VA hospital 2011-2018. In other words, existing operators were operators historically affiliated with VHA as indicated by their record of practice in CART-CL. *Radial-dominant operators* were defined as operators performing via the radial artery for at least 80% of their cases (i.e., *radial-dominant operators*), who were also new operators, meaning they had not been historically affiliated with VHA before 2015 (Figure 3). *Exposure to new radial-dominant* was the predictor of interest. We generated an indicator for hospitals where (a) legacy operators were exposed to an innovator (i.e., new, radial-dominant operator), or (b) existing operators were not exposed to an innovator. Our analysis is based exclusively on existing operators performance at both hospital types.

<b>Term</b>	<b>Definition</b>
<b>Radial-Dominant Operator</b>	<ul style="list-style-type: none"> <li>• Performs at 80% or greater radial access</li> </ul>
<b>Existing Operator</b>	<ul style="list-style-type: none"> <li>• Has practiced in VA healthcare system across all years, 2011-2018</li> </ul>
<b>New Operator</b>	<ul style="list-style-type: none"> <li>• Started practicing in VA in 2015</li> </ul>
<b>New, Radial-Dominant Operator</b>	<ul style="list-style-type: none"> <li>• Started practicing in VA in 2015</li> <li>• Performs 80% or greater radial access</li> </ul>
<b>Control Hospital</b>	<ul style="list-style-type: none"> <li>• Hospital contains legacy operators</li> </ul>
<b>Exposed Hospital</b>	<ul style="list-style-type: none"> <li>• Hospital contains legacy operators &amp; New, Radial-First Operator</li> </ul>

Figure 3. Chapter 2 Study Terms

*Patient-level independent variables* associated with cardiovascular health and radial access were also measured. These included indication of prior percutaneous coronary intervention (PCI), coronary artery bypass graft (CABG), acute coronary syndrome (ACS), prior cardiogenic shock, cardiovascular disease (CVD), chronic kidney disease (CKD), diabetes, congestive heart failure, hyperlipidemia, hypertension, peripheral artery disease, prior myocardial infarction, prior treatment, age, gender, and ethnicity.

Proportions for all patient-level independent variables were calculated for the overall sample and for procedures, stratified by hospital exposure status. To investigate whether there may be a meaningful relationship, or association, between radial access use of legacy operator and exposure to innovator, we performed a cross-sectional analysis. We used logistic regression to estimate the association between hospital exposure to a radial-dominant operator and use of radial-artery access site in CATH and PCI procedures. For each outcome, we fit two models: the first model was unadjusted, and the second model was adjusted for patient sociodemographic characteristics (age, gender, ethnicity), procedural characteristics (elective-staged, elective, urgent, salvage), and the patient-level independent variables listed above (e.g., prior PCI, CABG, etc.). All analyses were conducted using STATA 16.

## RESULTS

Among the 237,641 CATH procedures, 48.91% occurred in exposed hospitals, while 51.00% occurred in unexposed (i.e., control) hospitals. Patients represented by these procedures were predominantly white (80.1%) non-Hispanic (95.14%) males (97.25%) with a history of prior PCI (65%) and 66 years old on average. CATH procedures mainly occurred in VA hospitals that had cardiac surgery capabilities (70.72%) and considered staged elective procedures (72.05%) (Table 8.)

Among 89,499 PCI procedures, 51.78% occurred in exposed hospitals, while 48.22% occurred in unexposed hospitals. Patients receiving PCIs were also predominantly white (83.17%) non-Hispanic males (98.42%) with prior PCI (51.29%) and 66 years old on average. PCIs also mainly occurred in hospitals with cardiac surgery capabilities (66.52%) and occurred primarily as staged elective procedures (58.94%). PCIs had a higher proportion of elective cases (5.68%) than CATHs (.01%) (Table 9).

Hospital exposure to a new radial-dominant operator was associated with an increased likelihood of patients receiving procedures performed via radial artery, for both CATH and PCI, for all models. Estimates of association, as well as predicted probability of radial-artery access in procedures across hospital exposure status, are presented in Table 10 for both models.

In unadjusted models, existing operators in hospitals exposed to a new radial-dominant operator were 2.63 times more likely to perform CATH procedures via radial artery than legacy operators in hospitals without exposure (43.24% vs 22.48%, 95% CI:2.58-2.67). Adjustment for both sociodemographic and clinical covariates strengthened the association (OR 3.19; 95% CI:3.13-3.26). The estimated adjusted prevalence of radial-artery access CATH procedures taking place in hospitals exposed and unexposed to a new radial-dominant operator was 43.77% (95%CI: 43.49-44.06) and 22.19% (95%CI: 21.96-22.41), respectively.

In unadjusted models, legacy operators in hospitals exposed to a new radial-dominant operator were 2.80 times more likely to perform PCI procedures via radial artery than legacy operators in hospitals without exposure (37.17% vs 17.44%, 95% CI: 2.71-2.89). Adjustment for covariates strengthened the association (OR 3.25; 95% CI: 3.14-3.37). The estimated adjusted prevalence of radial-access PCI procedures taking place in hospitals exposed and unexposed to a new radial-dominant operator was 37.47% (95% CI: 37.01-37.94) and 17.33% (95% CI: 16.99-17.67), respectively.

In additional descriptive analyses, we observed the beginning of a downward trend, or apparent slowing, of radial-use rates in exposed hospitals. We also found that new radial-first operators tended to enter hospitals with higher baseline radial use rates, compared to unexposed hospitals (Figure 4).

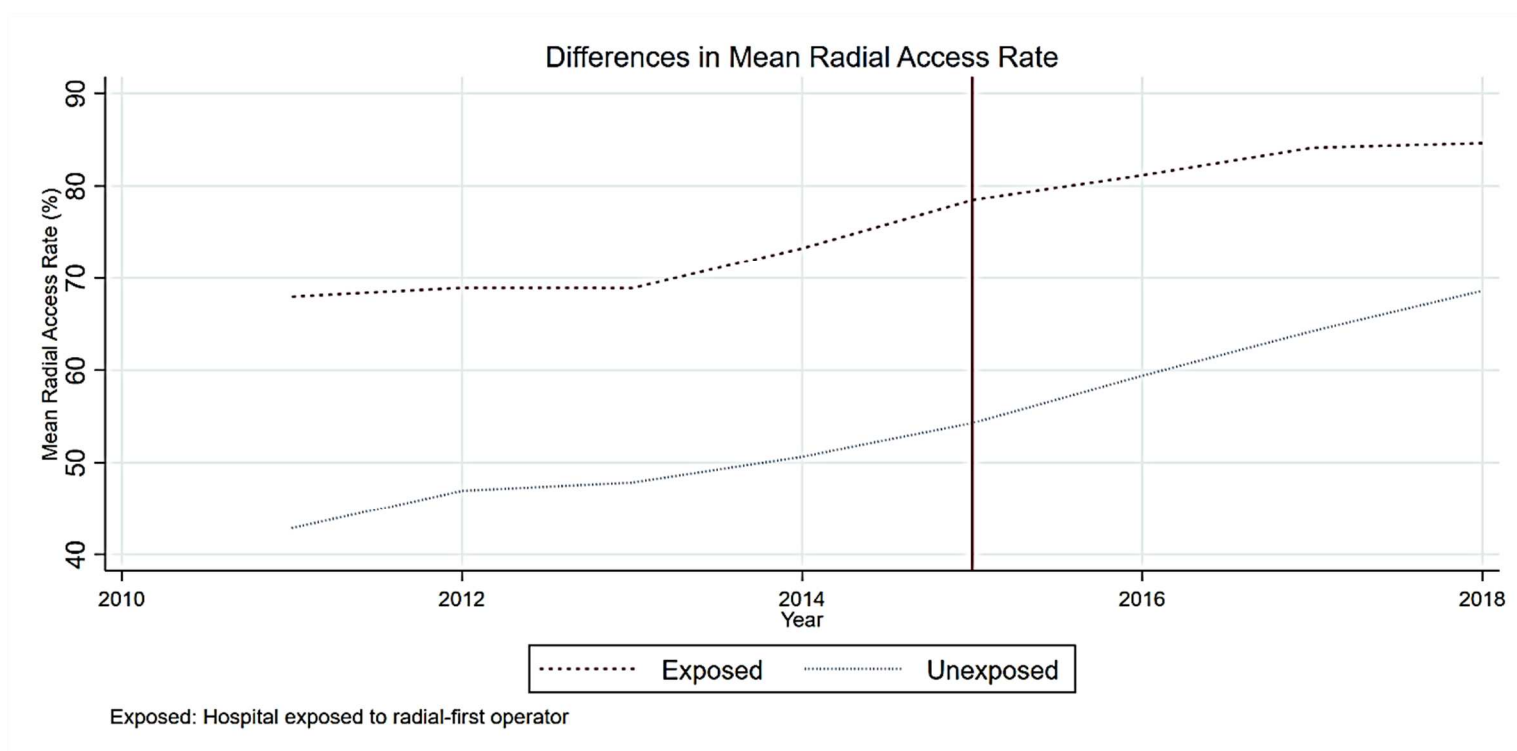


Figure 4. Differences in Mean Radial-Access Rate

## DISCUSSION

We examined how the arrival of a radial dominant operator—defined as a *new* operator with a preexisting high rate of radial access as the default mode of practice—at a VHA hospital might contribute to increase in radial-access use by existing operators in the same hospital. In this large sample of coronary procedures, arrival of an innovator was positively associated with adoption of the radial-access method. Our exploratory investigation revealed that there is indeed an association between observed existing practice patterns (use of radial access) and exposure to radial dominant. This important finding provides justification for further inquiry into the potential influence of peer-physician networks and support previous studies that demonstrate clinical decisions may be motivated by factors unrelated to the patient, but rather to peer networks.<sup>8,30,66</sup> These types of networks have qualities that can facilitate or impede the spread of an innovation. This includes the structure and quality of the network, and how much it is characterized by homophily (how alike the people in the network are), the role of opinion leaders,

champions, and boundary spanners (i.e., people with social ties both inside and outside of the organization).<sup>5</sup> These findings provide some support for our hypothesis that clinical decisions of existing physicians may be modified by interpersonal influences. They also provide some evidence of a selection effect; radial-dominant operators appear to join hospitals with higher baseline rates of radial access.

Separating the effects of *influence* and *selection* in behavioral subtleties is an enduring debate among scholars.<sup>5,67</sup> In the instance of *influence*, a new physician-peer could provide more information to an existing peer, perhaps reducing uncertainty during the decision-making process between femoral or TRA. On the other hand, *selection* could involve a scenario where new radial-dominant operators join higher radial-rate hospitals intentionally. Radial access as the default mode of access is still controversial in many practitioners' minds due to contradicting evidence<sup>68</sup> and steep technical learning curves involved in developing radial-access proficiency<sup>60,69</sup>. As an extension of homophily, it is possible radial-dominant physicians join hospitals where a community of radial-dominant operators exists. We also observed the beginning of a downward trend, or apparent slowing, of radial-use rates in exposed hospitals. We attribute this trend in part to the high baseline rate. An ideal rate has not been clinically defined, and TRA is not feasible in all cases, thus we expect there to be a ceiling; it's more difficult to improve when you're already ahead.

There are several limitations to our study. The sites of clinical practice in our work, VHA hospitals, generally have much lower volumes than community hospitals and VHA operators face less pressure to maintain high case volumes, both of which could affect adoption rates and results in fewer opportunities overall for operators to gain proficiency in the method. In this study, we focused on one aspect of the peer-physician environment (i.e., entry of a peer with preexisting high-radial rates) and recognize that there may be other factors to consider that we cannot assess due to data limitations. Nuances pertaining to more formal network characteristics (e.g., structure and quality) cannot be ascertained from real-time procedural records without additional data collection, supplemental qualitative investigation, and formal social network analyses. There are most certainly unmeasured confounders that may be implicated in the pathway between exposure to a new radial-dominant operator and use of radial

access by peers. Some of these include our inability to account for external influences, such as individuals performing procedures in both VHA and non-VHA hospitals, or the arrival of the new operator coinciding with other unobserved changes at the hospital, such as staff turnover.

## **CONCLUSIONS**

There was a strong and consistent association between hospital exposure to an innovator and radial access selection by legacy operators. These findings contribute to our understanding of radial access adoption in VHA hospitals. They also support additional experimental efforts in this area and highlight the importance of physician-peer influence in the physician's place of clinical practice. For instance, it would be interesting to examine whether the same association would manifest if new radial-dominant operators would be intentionally paired with low-adoption sites. Our findings also highlight physician-peer influence as a possible determinant of clinical decision-making among interventional cardiologists. Hospital exposure to innovative physician staff could be an important factor in adoption of innovations in interventional cardiology, overall. Future research is needed to understand the mechanism(s) by which new innovators influence existing peers. Lastly, our novel use of clinical data to assess a potential physician-peer network component supports future consideration of existing clinical data for opportunities to study network-related implementation processes.

## **LIST OF ABBREVIATIONS**

PCI- Percutaneous Coronary Intervention

CABG-Coronary Artery Bypass Graft

ACS-Acute Coronary Syndrome

CVD-Cardiovascular Disease

CKD-Chronic Kidney Disease

Table 8. Demographic characteristics and comorbidities of CART patients receiving cardiac catheterization (CATH) across hospital status

<b>Characteristic</b>	<b>Exposed Hospital* (n=116,253)</b>	<b>Unexposed Hospital* (n=121,388)</b>	<b>Total* (n=237,641)</b>
<b>Age (Years)</b>			
Mean (SD)	66.01 (9.13)	65.85 (9.11)	65.93(9.12)
Range	21.6-100.60	21.1-100.5	21.1-100.5
<b>Gender (%)</b>			
Male	97.25	97.35	97.30
Female	2.75	2.65	2.70
<b>Race (%)</b>			
American Indian or Alaskan Native	0.73	0.97	0.85
Asian	1.03	0.78	0.90
Black or African American	17.23	18.11	17.68
Native Hawaiian or Other Pacific Islander	0.37	0.61	0.49
White	80.65	79.2	80.08
<b>Ethnicity (%)</b>			
Hispanic	3.58	6.08	4.86
Non-Hispanic	96.42	93.92	95.14
<b>Procedure Priority (%)</b>			
Elective-Staged	.01	.01	.01
Elective	71.31	72.75	72.05
Emergent	2.83	3.03	2.93
Urgent	25.84	24.18	24.99
Salvage	0.02	0.04	0.03
<b>Prior PCI (%)</b>			
No	34.81	34.86	34.84
Yes	65.19	65.14	65.16
<b>Prior Treatment (%)</b>			
No	100	100	100
Yes	-	-	-
<b>Left Main (%)</b>			
No	100	100	100
Yes	-	-	-
<b>Bifurcation (%)</b>			
No	100	100	100
Yes	-	-	-
<b>Graft (%)</b>			
No	100	100	100
Yes	-	-	-
<b>Cardiac Surgery available (facility) (%)</b>			
No	38.04	20.88	29.28
Yes	61.96	79.12	70.72

\*All values represent proportions (%) unless otherwise specified (e.g., age)

Table 9. Demographic characteristics and comorbidities of CART patients receiving percutaneous coronary intervention (PCI)

<b>Table 9.</b> Sociodemographic characteristics and comorbidities of CART patients receiving Percutaneous Coronary Intervention (PCI) across hospital status			
<b>Characteristic</b>	<b>Exposed Hospital* (n=46,341)</b>	<b>Unexposed Hospital* (n=43,158)</b>	<b>Total* (n=89,499)</b>
<b>Age (Years)</b>			
Mean (SD)	67.02 (8.99)	66.72 (8.92)	65.93(9.12)
Range	21.7-100.5	26-100.5	21.7-100.5
<b>Gender (%)</b>			
Male	98.38	98.45	98.42
Female	1.62	1.55	1.58
<b>Race (%)</b>			
American Indian or Alaskan Native	0.63	1.00	0.82
Asian	1.05	0.83	0.94
Black or African American	13.93	15.14	14.56
Native Hawaiian or Other Pacific Islander	0.32	0.68	0.51
White	84.06	82.35	83.17
<b>Ethnicity (%)</b>			
Hispanic	3.42	6.47	5.00
Non-Hispanic	96.58	93.53	95.00
<b>Procedure Priority (%)</b>			
Elective-Staged	5.52	5.83	5.68
Elective	58.15	59.67	58.94
Emergent	5.75	5.80	5.78
Urgent	30.47	28.54	29.47
Salvage	0.10	0.16	0.13
<b>Prior PCI (%)</b>			
No	49.02	48.41	48.71
Yes	50.98	51.59	51.29
<b>Prior Treatment (%)</b>			
No	89.21	89.78	89.51
Yes	10.79	10.22	10.49
<b>Left Main (%)</b>			
No	97.26	97.18	97.22
Yes	2.74	2.82	2.78
<b>Bifurcation (%)</b>			
No	93.25	94.33	93.81
Yes	6.75	5.67	6.19
<b>Graft (%)</b>			
No	91.82	91.48	91.64
Yes	8.18	8.52	8.36
<b>Cardiac Surgery available (facility) (%)</b>			
No	33.48	13.48	23.12
Yes	66.52	86.52	76.88

\*All values represent proportions (%) unless otherwise specified (e.g., age)

Table 10. Unadjusted and adjusted associations between hospital exposure to radial-dominant operator and artery access site in a sample of VA patients

<b>Table 10.</b> Unadjusted and adjusted associations between hospital exposure to radial-dominant operator and artery access site in a sample of VA Patients (n=327, 140) **						
<b>A. CATH</b>	<b>OR</b>	<b>95% CI</b>	<b>EXPOSED</b>		<b>CONTROL</b>	
OUTCOME: Radial-Artery Access			<b>%</b>	<b>95% CI</b>	<b>%</b>	<b>95% CI</b>
<b>1a. Unadjusted</b>	2.63	(2.58-2.67)	43.24	(42.94-43.54)	22.48	(22.25–22.72)
<b>2a. Adjusted for Sociodemographic Characteristics and Cardiac Comorbidities*</b>	3.19	(3.13–3.26)	43.77	(43.49–44.06)	22.19	(21.96–22.41)
<b>B. PCI</b>						
OUTCOME: Radial-Artery Access						
<b>1b. Unadjusted</b>	2.80	(2.71–2.89)	37.17	(36.69–37.65)	17.44	(17.09–17.78)
<b>2b. Adjusted for Sociodemographic Characteristics and Cardiac Comorbidities*</b>	3.25	(3.14–3.37)	37.47	(37.01–37.94)	17.33	(16.99–17.67)

*\*Models were adjusted for time, age, gender, race/ethnicity, procedure priority, prior PCI, prior coronary artery bypass graft (CABG), ACS, BMI, prior cardiogenic shock, cardiovascular disease (CVD), chronic kidney disease (CKD), diabetes, congestive heart failure (CHF), hyperlipidemia, hypertension (HTN), peripheral artery disease (PAD), prior myocardial infarction (MI), prior treatment, left main, bifurcation, graft, cardiac surgery.*

*\*\*All ORs had P-values <0.001.*

*OR=odds ratio*

*CI=confidence interval*

## CONCLUSIONS

This study was designed to address gaps in health systems research by assessing potential factors underpinning cath lab procedure adoption among interventional cardiologists. Communication of clinical decisions among physician peers creates channels of information exchange in health systems; flows of information exchange play an important role in determining how systems operate; it's possible physician operators may exist at a leverage point that may facilitate or impede innovation and sustained change.<sup>70,71</sup> My research aimed to quantitatively examine individual and interpersonal factors related to a physician operator's work environment that may contribute to adoption of cath lab procedures in an integrated health system. Robust clinical-data available at VHA allowed us to study provider-level factors associated with practice patterns that reflect physician decisions to adopt cath lab procedures. This study examined the source of practice pattern differences across VHA (Aim 1), individual (Aim 2), and interpersonal (Aim 3) factors hypothesized to be associated with physician operator peer-networks and possible determinants of physician decision making at VA.

The best way to promote new and evolving technologies in the cath lab, and among physicians in general, is unclear. Potential drivers cath lab procedure adoption had yet to be assessed in the context of interventional cardiology, but generally and especially in a defined population of hospitals, providers, and patients over time. In this descriptive analysis of potential care-level factors affecting innovation-adoption, we observed that *operators* could potentially affect the use of cath lab procedures. Clinical decisions are expected to be primarily motivated by patient characteristics; however, given the observed operator-level contributions, further exploration into whether provider personal preferences play a more meaningful role, appears warranted. For example, preference-motivated choices could amount to detectable differences in a system's overall adoption of new procedures. Our results also suggest that there are potentially more levels, or factors, contributing to these differences that we have not yet

accounted for. One example of this could be operators who also hold appointments at different healthcare systems (e.g., university medical centers); the other system's enforced practices might have an impact on an operator's choices at VHA that we cannot measure. These findings also corroborate the premise that all levels of care play some role, and that there may be overlap between them. For example, we observed most variability contribution from the patient level, however this might be due to patient advocacy instead of their current clinical health indicators, which might be entirely dependent on the hospital's communication with the patient on new practices—a hospital-level factor overlapping a patient-level one.

An operator's career stage was associated with likelihood of using 4 practices—radial access, FFR/iFR, intravascular imaging, atherectomy—across CATHs and PCIs overall, after adjusting for patient factors. The higher likelihood of use among mid-career operators was unexpected; we had posited that all later career stages would be less likely than early-career operators to adopt procedures. We learned mid-career operators, or those 6-10 years removed from formal training, were more likely than early-career peers to use these practices. On the other hand, operators 11 years removed from formal training or higher (late-career) were less likely than early-career peers to use the same procedures. The one exception to our findings was in use of atherectomy, which both late- and mid-career operators were more likely to perform than early-career operators. Again, this stood in contrast to our initial hypothesis that early-career operators would be more likely to adopt procedures than mid- and late-career peers. It suggests further inquiry into how career stage can be defined and perhaps how that may be different among operators at an individual level.

We also examined how the arrival of a radial dominant operator—defined as a new operator with a preexisting high rate of radial access as the default mode of practice—at a VHA hospital might contribute to increase in radial-access use by existing operators in the same hospital. In this large sample of coronary procedures, arrival of an innovator was positively associated with adoption of the radial-access method. Our exploratory investigation revealed that there is indeed an association between observed existing practice patterns (use of radial access) and exposure to radial dominant. However, it raised questions about the effect of peer influence versus self-selection given operators with higher pre-

existing radial-access rates were more likely to join hospitals that also had higher pre-existing radial-access rates. The questions of influence and selection are not mutually exclusive and are challenging to disentangle. Nonetheless, our findings raise potentially interesting areas of future research and call for the integration of formal social network analysis in clinical decision-making research, and in health services research in general. One potential approach would be a mixed-methods assessment of peer influence; it would be helpful to generate further understanding as to how these networks are defined by providers themselves, not merely who they may recorded working with on several cases. Lastly, our novel use of clinical data to assess a potential physician-peer network component supports future consideration of existing clinical data for opportunities to study network-related implementation processes, in addition to supplemental qualitative data collection.

Further analysis of relative advantage, cost, and other characteristics pertaining to the evolving cath lab procedures examined was beyond the scope of this work. The illustrated differences in adoption rate over time by type of innovation indicates that some of what drives adoption is likely unrelated to procedure-specific characteristics; more research is needed to understand the interaction between specific innovation characteristics, such as cost, and each of the levels contributing to uneven adoption, including the ones we studied here—hospital, operator, patient—and others we were unable to study. Cost of equipment necessary to perform an atherectomy, for example, could be important to hospitals, but irrelevant to providers or patients. Other studies have also shown that characteristics earlier on in the life course of the procedure itself, such as the manufacturing stage, might also have consequences for what is ultimately adopted.<sup>72</sup>

Clinicians take the Hippocratic oath, promising to practice in the best interest of the patient. This is not as simple as it seems; there are many factors influencing what the clinician ultimately perceives to be in the best interest of the patient. The less obvious and I believe equally, if not more, important factor could be the influence of peer-to-peer dynamics that expose basic human tendencies to which clinicians are not immune. The current state of health care in the United States, despite numerous evidence-based solutions for many of its problems, serves as proof that medicine may not always be as clear-cut and

exclusively scientifically driven as we would like. In this body of work, we have taken the first step to acknowledging and studying these less visible but potentially powerful factors that may be more integrally implicated in the process by which changes in medical practice happen. We have pushed to boundary and asked, “Why operators in the cath lab have decided to adopt certain procedures, and what about these operators might be associated with these decisions?”, advancing both DOI and improvement science, which aims to make the process of how change happens clearer and more explicit so that assimilation of high-quality care options occurs more effectively.

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## VITA

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