# Characteristics of Early and Late Adopting Hospitals Providing Percutaneous Coronary Intervention in Taiwan

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***Background***—Studies in the United States suggested that the characteristics of hospitals providing percutaneous coronary intervention (PCI) differed from those not providing PCI. However, little is known on the differences between the characteristics of early-adopting hospitals and those of late-adopting hospitals, and on their potential impacts on PCI volume and access.

***Methods and Results***—We used inpatient claims data from 1997 to 2012 from the Taiwan National Health Insurance program to identify the hospitals offering PCI. Geographic information systems (GIS) were used to determine the population access to PCI hospital. As of 2012, 88 hospitals were capable of providing PCI. On the basis of the year that the hospitals started providing PCI, 32 hospitals were designated as early adopters (before 1998), 23 as early majority (1998–2002), 24 as late majority (2003–2007), and 16 as laggards (2008–2012). Hospitals that adopted PCI later were smaller in size and closer to an existing PCI hospital and had lower PCI volumes performed and less bypass surgery support. The median PCI volumes in 2012 were n=706, 330, 138, and 81 in early adopters, early majority, late majority, and laggards, respectively. Despite the low volume of PCI performed in laggard hospitals, the percentage with ST-elevation myocardial infarction and acute myocardial infarction as principal discharge diagnosis was higher than their early-adopting hospital counterparts. The percentage of the Taiwanese population living within 40 km of PCI hospitals (appropriate access defined in this study) was 95.7% in 1997 and 98.0% in 2002, and this has remained unchanged since 2002.

***Conclusions***—The characteristics of early-adopting hospitals differed from those of late-adopting hospitals. Despite lower PCI volume performed in late-adopting hospitals, many of them are in remote areas and provide needed and timely services for patients with acute myocardial infarction. **(*J Am Heart Assoc*. 2015;4:e002840 doi: 10.1161/JAHA.115.002840)**

**Key Words:** access to care • angioplasty • diffusion of innovation • geographic information system • mapping • percutaneous coronary intervention

In the United States, the number of hospitals providing percutaneous coronary intervention (PCI) has increased in the past 2 decades.[1–7] According to the American Hospital Association Annual Survey, 1176 US hospitals were capable of performing PCI in 2001; this number increased to 1739 in 2008, an increase of >40%.[4,5] To explain the rapid diffusion of PCI adoption in US hospitals, Vaughan-Sarrazin et al[8] suggested that PCI is favored over coronary artery bypass graft (CABG) because PCI is easy to learn and implement, has a high reimbursement rate, and requires only slight modifications of existing techniques, such as drug-eluting stents.

Another study indicated that the newer and larger hospitals equipped with expensive medical technology were more likely to adopt PCI.[5] However, little is known about the differences between the characteristics of early- and late-adopting hospitals. According to Everett Rogers' theory of the diffusion of innovations, facilities can be classified into 5 categories based on their timing of adoption of new technology: innovators, early adopters, early majority, late majority, and laggards.[9] The first objective of this study was to examine whether the characteristics of the late-adopting hospitals providing PCI differed from those of the early-adopting hospitals.

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As indicated by Rogers, diffusion of innovations is a means to an ultimate end: consequences that result from adopting an innovation. Consequences are the changes that occur to an individual or a social system from adapting or rejecting an innovation.[9] In terms of diffusion of PCI, the end goals are to improve PCI accessibility, provide high-quality PCI in all areas, and in the long run, decrease the overall mortality rate in patients with coronary artery disease. However, as argued by Concannon et al,[5] in an era of flat use of elective PCI procedure, systematic duplication (ie, implementing new PCI programs targeting neighborhoods already served by an existing program) reduces average PCI volumes and results in lower procedure quality and worse outcomes for patients with coronary artery disease. The second objective of this study was to examine whether late adopting hospitals had different effects on PCI volume and access compared with their early-adopting counterparts.

## Methods

### Data Sources

The main data source for this study was obtained from the Taiwan National Health Insurance Research Database (NHIRD), which is maintained by the National Health Research Institutes, Taiwan. The NHI Program was introduced in 1995 and covers more than 99% of the Taiwanese population. The NHIRD includes outpatient and inpatient claims data (including data on diagnosis and procedure codes, patient characteristics, physicians, clinical settings, and various service fees) for 1997–2012.[10] Because all patients receiving PCI in Taiwan were required to be hospitalized for observation, we only used the inpatient claims data from the NHRID. The second data source we used was the Medical Facility Open Information Query System maintained by the Ministry of Health and Welfare; it was used to obtain information on hospital characteristics unavailable in the NHIRD.[11] This study was approved by the Institutional Review Board of Cheng Hsin General Hospital (CHGH-IRB No. (424)103-1). As this study used secondary administrative data the requirement that subjects should give informed consent was waived.

### PCI Hospitals

We used the *International Classification of Disease, the Ninth Revision, Clinical Modification* (ICD-9-CM) codes 36.01, 36.02, 36.05, 36.06, and 36.09 (Taiwan NHI does not use the ICD-9-CM codes 00.66, 36.00, and 36.07 for PCI, which are used in US hospitals) to determine the number of PCIs performed per hospital per year.

According to innovation diffusion theory, we classified the PCI hospitals into 4 categories on the basis of the hospitals' first-year claims data on PCI reimbursements: (1) the early adopters, which started providing PCI before 1998; (2) the early majority, which started providing PCI between 1998 and 2002; (3) the late majority, which started providing PCI between 2003 and 2007; and (4) the laggards, which started providing PCI between 2008 and 2012. Information on the number of hospitals providing PCI before 1997 were derived from a historical review and personal communication.[12]

The characteristics of hospitals included level of hospitals (tertiary referral hospital, secondary referral hospital, and community district hospital), ownership of hospital (public versus private), number of hospital beds, number of PCI performed, having CABG surgery facility (ICD-9-CM code 36.1X and 36.2), percentage of PCI performed with principal discharge diagnosis as acute myocardial infarction (AMI). We did not distinguish ST-elevation myocardial infarction versus non-ST-elevation myocardial infarction because of unreliable coding. The information on the number of hospital beds was obtained from the query system of Ministry of Health and Welfare.[11] The information on other characteristics was derived from the inpatient claims data. We used ICD-9-CM codes 36.1x and 36.2 to identify hospital having CABG surgery facility, and ICD-9-CM code 410.xx for AMI diagnosis.

### PCI Volume and Access

We first calculated the PCI volumes per hospital per year to examine the differences in PCI volumes between the early and late adopting hospitals.[13,14] We then used a geographic information system (GIS) to geocode these hospitals to determine whether public accessibility to PCI improved between 1997 and 2012. Taiwan comprises 368 districts, which are the basic administrative units. If the GIS-estimated linear distance (crow's fly distance) between the district centroid and the nearest PCI hospital was <40 km (≈25 miles), the entire population of that district was considered to have appropriate access to PCI, and if this distance >40 km, the entire population of the district was considered to be inappropriate access to PCI. We then computed the percentages of the Taiwanese population with appropriate access to PCI in 1997, 2002, 2007, and 2012.

Study in the US used 40 miles as threshold to assess the accessibility.[6] As Taiwan is a small island with high-density population, we used 25 miles as the threshold to assess the accessibility of PCI services. Moreover, we calculated the GIS-estimated linear distance between new PCI hospitals and the nearest old PCI hospitals to assess the problem of duplication of PCI hospitals.

Taiwan (35 980 km$^2$) is similar in size to the US state of Maryland (32 133 km$^2$). However, the population of Taiwan (23 million) is nearly 4 times that of Maryland (6 million). Except in certain mountainous regions, most of Taiwan is accessible by public transportation. The National Health Insurance Administration, thus, classified Taiwan into 6 medical regions, namely Taipei, Northern, Central, Southern, Kauping, and Eastern; this classification is similar to the 306 hospital referral regions in the United States. To assess regional disparities in the abundance of PCI hospitals, we calculated the number of PCI hospitals per 1 million persons in each medical region in 1997, 2002, 2007, and 2012.

## Statistical Analyses

We used the chi-square test to examine if there were significant differences in the characteristics (level of hospital, ownership of hospital, bed capacity of hospital, percentage of hospitals with CABG support in 2012, and the percentage of PCI performed in 2012 with AMI as principal diagnosis) of the 4 PCI hospital categories, in which the innovators and early adopters were combined into a single category. We used the Kruskal-Wallis test to assess whether the median PCI volumes and median distance between new hospitals with existing hospitals in 2012 differed among the 4 PCI hospitals categories.

## Results

The number of hospitals adopting PCI by year is illustrated in Figure 1; 2 surges were observed, the first was in 1996–1997 and the second in 2010–2011. According to the claims data, 32 hospitals provided PCI in 1997, and this number increased substantially by 2.8-fold to 88 in 2012. Depending on the year that hospitals started providing PCI, 32 were classified as early adopters (before 1998), 23 as early majority (1998–2002), 24 as late majority (2003–2007), and 16 as laggards (2008–2012).

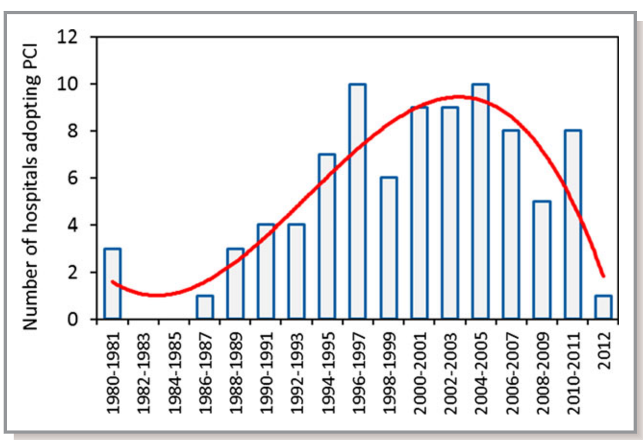


**Figure 1.** Number of hospitals adopting percutaneous coronary intervention (PCI) by year in Taiwan.

The characteristics of the 4 PCI hospital groups are presented in Table 1. A prominent increase in district community hospitals (n=7) providing PCI services was noted since 2008. The later the hospitals adopted PCI, the smaller their sizes and the closer they were to existing PCI hospitals, the lower the percentage with CABG surgery support, the lower the volume of PCI performed, and the higher the percentage of PCI performed with AMI as principal discharge diagnosis.

The descriptive statistics of the PCI volumes in 2012 for the 4 PCI hospital categories are illustrated in Figure 2. The minimum, median, and maximum PCI volumes in 2012 were 197, 706, and 1605 for the early adopters; 100, 338, and 836 for the early majority; 34, 138, and 625 for the late majority; and 15, 81, and 365 for the laggards, respectively. The annual PCI volumes of 15 hospitals was <100, and 13 of these hospitals were laggards. One laggard PCI hospital adopted PCI in 2009 but stopped offering the procedure in 2012.

To assess whether the new PCI hospitals were located in an area where neighboring hospitals already offered similar procedures, we tracked each hospital providing PCI on a map (Figure 3). As shown in Figure 3B, between 1998 and 2002, only 2 early majority hospitals had a distance between the new PCI hospital and its nearest existing PCI hospital higher than 20 km (≈12.4 miles): one each in the Eastern (81.3 km, ≈50.5 miles) and Kaupin regions (20.8 km, ≈12.9 miles). Between 2003 and 2007, no late majority hospitals had a distance exceeding 20 km from the nearest existing PCI hospital, and 6 new PCI hospitals had distances between 10 and 20 km (Figure 3C). Between 2008 and 2012, only one laggard hospital in the Central Region had a distance exceeding 20 km (29.7 km, ≈17.3 miles), and 3 new PCI hospitals had distances between 10 and 20 km (Figure 3D).

With regard to public accessibility to PCI, in 1997, ≈95.7% of the population lived within a distance of 40 km (≈25 miles) from a PCI hospital; this percentage was 98.0% in 2002, 98.0% in 2007, and 98.2% in 2012. Table 2 illustrates regional variations in PCI hospitals per 1 million population by year. The variation in PCI center density among 6 regions was small in 1997 (1.1–1.9) and a little bit larger in 2012 (3.1–5.3).

## Discussion

The findings of this nationwide descriptive study in Taiwan indicate that the characteristics of the early-adopting PCI hospitals differed from those of the late-adopting hospitals. The late-adopting hospitals were smaller in size and had lower PCI volumes and lower percentage of having CABG surgery support; yet had higher percentage of PCI performed with AMI as principal discharge diagnosis. Despite the mild increase in

**Table 1.** Characteristics of Hospitals Providing Percutaneous Coronary Intervention (PCI) by Year Providing PCI Services in Taiwan

| Characteristics (Year Offering PCI Service) | Early Adopters (Before 1998) | Early Majority (1998–2002) | Late Majority (2003–2007) | Laggards (2008–2012) | *P* Value |
|---|---|---|---|---|---|
| Number of hospitals | 32 | 23 | 24 | 16 | |
| Level of hospital | | | | | |
| Tertiary referral hospitals | 15 | 2 | 0 | 0 | |
| Secondary referral hospitals | 17 | 21 | 23 | 9 | |
| District community hospitals | 0 | 0 | 1 | 7 | <0.001 |
| Ownership of hospital | | | | | |
| Public | 13 | 5 | 9 | 4 | |
| Private | 19 | 18 | 15 | 12 | 0.4147 |
| Number of beds in 2012 | | | | | |
| ≤500 | 0 | 2 | 3 | 11 | |
| 501 to 750 | 6 | 11 | 12 | 4 | |
| 751 to 1000 | 6 | 4 | 4 | 0 | |
| 1001 to 1250 | 9 | 2 | 3 | 1 | |
| ≥1251 | 10 | 4 | 2 | 0 | <0.001 |
| Median distance (km) between new and nearest old PCI hospital | | 4.8 | 3.6 | 3.2 | 0.1604 |
| % of hospitals providing CABG in 2012 | 75.0 | 69.6 | 33.3 | 6.3 | <0.0001 |
| Median PCI volumes in 2012 | 706 | 330 | 138 | 81 | <0.001 |
| % of PCI performed in 2012 with AMI as principal discharge diagnosis | 30.4 | 32.2 | 36.9 | 38.3 | <0.0001 |

AMI indicates acute myocardial infarction; CABG, coronary artery bypass graft.

population access to PCI access during the past decade, some of laggard PCI-adopting hospitals are in remote areas and provide needed and timely services for AMI patients.

## Diffusion of PCI Adopting

In contrast to the United States, where 1739 hospitals provided PCI in 2008,[5] only 88 hospitals provided PCI in Taiwan in 2012.

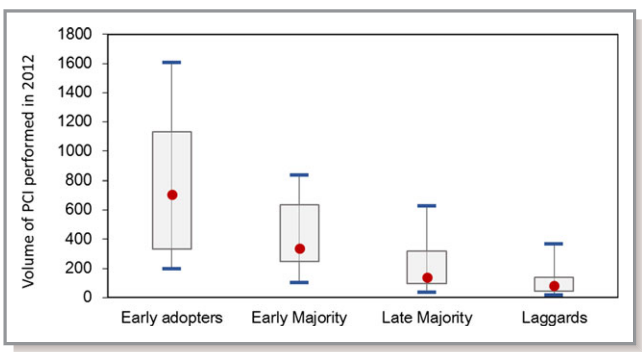


**Figure 2.** The percentage of PCI volume—100%, 75%, 50%, 25%, and 0%—observed in early adopters, early majority, late majority, and laggard PCI hospitals, respectively, in 2012 in Taiwan.

Following Rogers' classification, 3 "innovators" (ie, Taipei Veterans General Hospital, Chang Gang Memorial Hospital, and National Taiwan University Hospital) started offering PCI in 1980. By the early 1990s, almost all tertiary referral hospitals with >1000 hospital beds have provided PCI services. The adoption of PCI accelerated after bare-metal stents were introduced to Taiwan in 1995, many large secondary referral hospitals started to provide PCI services. A slowdown of increase was noted in 1998–1999 because of the change of PCI insurance reimbursement from fee-for-services (FFS) to diagnosis-related groups (DRG) in 1999.[15] As the total payments under DRG regime were better than FFS for PCI services, a return to the growth curve in 2010–2011 was noted.

The second surge in the number of hospitals offering PCI in 2010–2011 (Figure 1), which was initiated by the government. The Door-to-Balloon Alliance, which included 15 leading PCI hospitals, initiated by the Taiwan Joint Commission on Hospital Accreditation was launched in 2008.[16] The hospitals' ability to provide primary PCI facilities for patients with STEMI was mandated by the commission as a criteria for obtaining a high emergency accreditation level. Furthermore, the Ministry of Health and Welfare encouraged district hospitals in remote areas to provide PCI services.

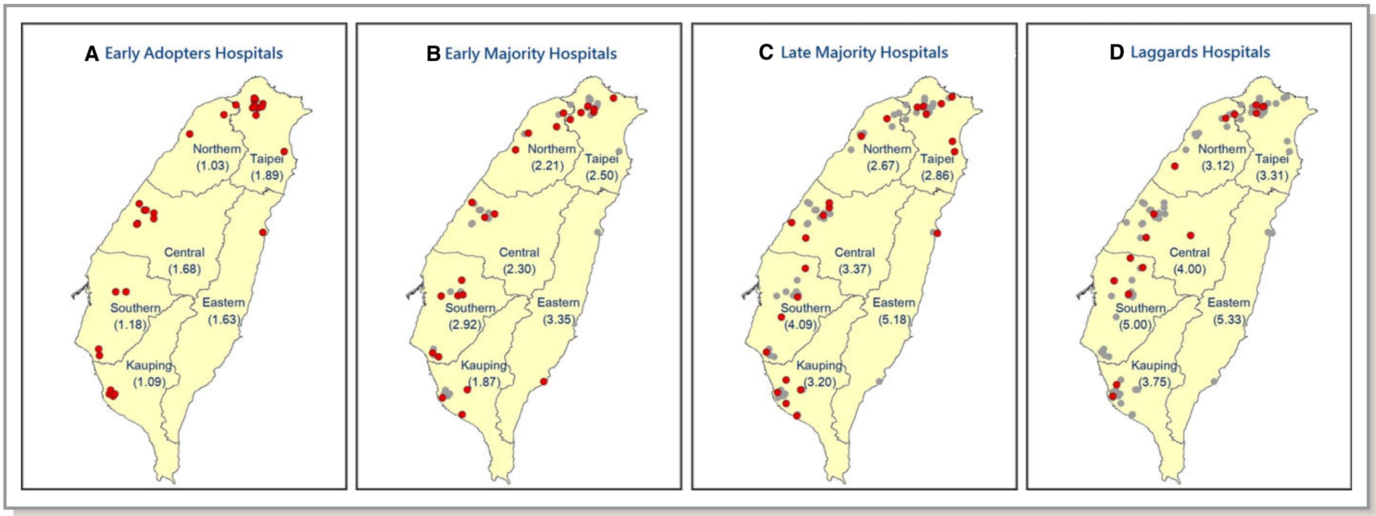


**Figure 3.** Locations of hospitals (based on the PCI starting year) offering PCI in Taiwan (A) early adopters (before 1998); (B) early majority (1998–2002); (C) late majority (2003–2007); (D) laggards (2008–2012). The number in parentheses in each medical region is the number of PCI hospitals per 1 million persons in that region for the years 1997 (A), 2002 (B), 2007 (C) and 2012 (D). The ● red dot indicates the location of new PCI hospitals and ● the gray dot indicates the location of existing PCI hospitals in the given study period.

## PCI Volume

Regarding the minimum PCI volume standard, the 2013 American College of Cardiology/American Heart Association/Society for Cardiovascular Angiography and Interventions clinical competence statement on PCI recommended that PCI be performed only by operators with an annual volume of >50 procedures at hospitals with an annual volume exceeding 200 procedures.[17] In 2012, >one-third (32 of 88) of all PCI hospitals in Taiwan had annual volumes <200. Furthermore, 9 of the 16 laggard hospitals had an annual PCI volume of less than 100. Hence, regular monitoring of the PCI quality at the laggard PCI hospitals seems warranted. However, many of these low PCI volume laggard hospitals are in remote areas with small populations and with relatively low PCI demand. According to Table 1, the laggard hospitals had a statistically significant higher percentage of PCI performed with AMI as principal discharge diagnosis than the early-adopting hospitals, the difference in percentage was not huge. These low-PCI volume laggard hospitals play an important role in providing needed and timely services for people with AMI in remote areas. Actually, the in-hospital mortality rate of AMI patients has been reduced significantly in those areas that have utilized this approach.[18]

**Table 2.** Number of Hospitals Providing Percutaneous Coronary Intervention (PCI) Per 1 Million Population in 6 Medical Regions in Taiwan

| Medical Region | 1997 | 2002 | 2007 | 2012 |
|---|---|---|---|---|
| Taipei | 1.9 | 2.5 | 2.9 | 3.3 |
| Northern | 1.0 | 2.2 | 2.7 | 3.1 |
| Central | 1.7 | 2.3 | 3.4 | 4.0 |
| Southern | 1.2 | 2.9 | 4.1 | 5.0 |
| Kauping | 1.1 | 1.9 | 3.2 | 3.7 |
| Eastern | 1.6 | 3.4 | 5.2 | 5.3 |

## PCI Access

Regarding PCI accessibility, 88% of the US population lived within a distance of 64 km (≈40 mi) from a PCI hospital in 1997, and the percentage increased to 93% in 2008.[5] A study in Michigan reported that of the 12 hospitals that were upgraded to provide primary PCI procedures, only 3 were located at least 32 km (≈20 miles) from another primary PCI hospital, accounting for a 4.3% improvement in public accessibility, whereas the remaining 9 hospitals increased the accessibility by only 0.5%.[19]

Geographically, Taiwan is a small country with a high-density population and a convenient public transportation system. The percentage of the population living within a range of 40 km (≈25 miles) from a PCI hospital was already high (95.7%) in 1997, and only 32 early-adopter hospitals provided PCI. The percentage increased to 98.0% in 2002, after 23 hospitals started providing PCI between 1998 and 2002. Between 2002 and 2012, 40 new hospitals started providing PCI; however, no substantial improvement in public accessibility to PCI was observed.

Another measure of PCI accessibility was PCI center density: the number of PCI hospitals per 1 million population in a given region. A US study reported a wide state-to-state variation in PCI center density from 3.2 in Vermont and 3.6 in Minnesota to 12.1 in West Virginia and 11.6 in Louisiana, with a median of 6.95.[7] Contrarily, no such substantial regional variation in PCI center density, which ranged from 3.12 in the Northern region to 5.33 in the Eastern region in 2012, was noted in Taiwan (Table 2 and Figure 3).

## Limitations

Several limitations should be noted in interpreting the findings of this study. First, the arbitrary use of the year that each hospital started providing PCI into 4 time periods (1997, 1998–2002, 2003–2007, and 2008–2012) for classifying the PCI hospitals was the first limitation. However, we could not find any superior classification method; Rogers also arbitrarily used statistical standard deviation to classify the underlying population of adopters into 5 categories.[9]

Second, we used the crow-fly distance instead of road distance or drive time between the population and the nearest PCI hospitals as a proxy measure of PCI accessibility, which might generate results that are different from approaches that use actual transportation time as the basis of measurement, which is important for treatment of patients with AMI. However, the transport time to a PCI facility can be affected by many other factors, such as traffic, time of the day, and other factors, which vary considerably.[20]

Third, as the geographic size of the 368 districts in Taiwan varied greatly from 9 persons per $km^2$ in Soulin Township, Hualien County to 21 950 persons per $km^2$ in Central District in Taichung City, which had different implications with regard to the distance of 40 km used for assessing access. Furthermore, caution should be exercised in interpreting PCI center density as an indicator of population accessibility to PCI. The population in the Eastern region was 0.56 million in 2012, which is relatively small compared with the other regions in Taiwan: 7.5 million in the Taipei region, 3.5 million in the Northern region, 4.5 million in the Central region, 3.4 million in the Southern region, and 3.7 million in the Kaupin region.

## Conclusions

Many evidence-based innovations in health care, as indicated by Berwick,[21] implemented successfully in one location often disseminate slowly. By contrast, the diffusion of PCI in the United States and Taiwan occurred quite rapidly. As the theory suggests that diffusion depends upon many things beyond the innovation itself (PCI in this case), but also upon the adopters (explored in this paper), communication channels, time, and the social system (initiation by government in Taiwan). However, as suggested by Rogers, concern about the consequences of the diffusion of innovations should not be neglected. Our data reveal that the late-adopting hospitals were smaller and had lower PCI volumes performed. However, these low PCI volume laggard hospitals played an important role in providing needed and timely services for people with AMI in remove areas. The Ministry of Health and Social Welfare and National Health Insurance Administration should provide needed support for these low-PCI volume hospitals in remote areas to ensure the quality of PCI performed.

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## Disclosures

None.

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