

Costs associated with transradial access and same-day discharge after percutaneous coronary intervention: a systematic review and meta-analysis

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Transradial access for PCI (TRI) along with same day discharge (SDD) is associated with varying estimates of cost savings depending on the population studied, the clinical scenario and application to low-risk vs high-risk patients. A summary estimate of the true cost savings of TRI and SDD are unknown. We searched the PubMed, EMBASE®, CINAHL® and Google Scholar® databases for published studies on hospitalization costs of TRI and SDD. Primary outcome of interest in all included studies was the cost saving with TRI (or SDD), inflation-corrected US\$ 2018 values using the medical consumer price index. For meta-analytic synthesis, we used Hedges' summary estimate (g) in a random-effects framework of the DerSimonian and Laird model, with inverse variance weights. Heterogeneity was quantified using the I^2 statistic. The cost savings of TRI from four US studies of 349,757 patients reported a consistent and significant cost saving associated with TRI after accounting for currency inflation, of US\$ 992 (95% CI US\$ 850–1,134). The cost savings of SDD from six US studies of 1,281,228 patients, after inflation-correcting to the year 2018, were US\$ 3,567.58 (95% CI US\$ 2,303–4,832). In conclusion, this meta-analysis demonstrates that TRI and SDD are associated with mean cost reductions of by approximately US\$ 1,000/patient and US\$ 3,600/patient, respectively, albeit with wide heterogeneity in the cost estimates. When combined with the safety of TRI and SDD, this meta-analysis underscores the value of combining TRI and SDD pathways and calls for a wide-ranging practice change in the direction of TRI and SDD.

1. Introduction

The practice of percutaneous coronary intervention (PCI) in the United States is evolving. Over 25 years ago, Campeau in Canada contemporaneous with Kiemeneij and Laarman in The Netherlands, began explorations into the possibility of using transradial access [1–7]. Since then rapid advances in this technique and related devices have catapulted transradial intervention (TRI) to an internationally accepted benchmark and a clinically viable approach to PCIs [8–11]. A series of studies have demonstrated the superiority of TRI compared to conventional transfemoral intervention (TFI) in terms of reduced risk of adverse outcomes and shorter lengths of hos-

pital stays [12–23]. A recent Scientific Statement from the American Heart Association highlights these advantages and recommends TRI even in patients with acute coronary syndrome (ACS) [24]. Additionally, over a decade ago, Society for Cardiovascular Angiography and Interventions (SCAI) published an expert consensus in the form a decision matrix to facilitate same-day discharge (SDD) after PCI [25]. Being especially suited for TRI, this SDD approach is highly attractive to patients, physicians and hospitals [26–28]. A recent meta-analysis has shown that in patients with stable coronary artery disease, SDD is not associated with adverse outcomes. The SDD approach has thus led to reduced practice variations around post-PCI care without affecting the rates of adverse outcomes after PCI [28–31].

Both TRI and SDD have added economic benefits and have been shown to reduce costs associated with PCI [1, 32–40]. From the perspective of the hospitals, better resource utilization and shorter duration of hospital stay can yield substantial reductions in hospitalization costs. While there is a paucity of controlled trials that specifically address hospitalization costs in the context of TRI and SDD, several observational studies have demonstrated reduced hospitalization costs in this regard [15, 32–34, 36, 41–43]. However, these studies have provided varying estimates of cost savings depending on the population studied, the clinical scenario and application to low-risk vs high-risk patients. Accordingly, the true cost savings of TRI and SDD have not been defined. To address this knowledge gap, we report our results from a systematic review and meta-analytic synthesis of the published literature on the estimated economic impact of TRI and SDD in the United States. Our objectives were twofold: to determine a meta-analytic summary estimate of the cost savings associated with TRI and SDD; and to investigate the heterogeneity across studies in cost-savings associated with TRI or SDD.

Cost saving of TRI				Cost saving of SDD			
Search Strategy		N		Search Strategy		N	
1. cost AND percutaneous AND coronary AND intervention AND (radial OR transradial)		81		1. cost AND percutaneous AND coronary AND intervention AND ((same AND day AND discharge) OR (same-day AND discharge))		30	
2. 1 NOT review		59		2. 1 NOT review		23	
3. 2 AND (benefit OR saving OR reduction OR analysis)		42		3. 2 AND (benefit OR saving OR reduction OR analysis)		16	
Direct comparison of TRI and TFI		11		Direct comparison of SDD and NSDD		10	
Non US Studies	7	US Studies	4	Non US Studies	4	US Studies	6

Fig. 1. Protocol for including studies in this systematic review and meta-analysis. Black boxes indicate studies that were included in the meta-analyses. N, number of articles.

2. Methods

2.1 Data extraction

We searched the PubMed, EMBASE®, CINAHL® and Google Scholar® databases for published studies on hospitalization costs of TRI and SDD. Fig. 1 shows the flowchart used to include studies into this systematic review and meta-analysis. A combination of literature search and snowballing methods were used to include potential studies into this review. Each included study was independently reviewed by the two coauthors (AA and HK) for completeness and to extract the information needed for meta-analysis. We included all published studies related to cost savings of TRI or SDD in the systematic review but for the meta-analyses we restricted to the US studies only to avoid comparisons across different healthcare models.

2.2 Statistical analysis

Primary outcome of interest in all included studies was the absolute cost savings associated with TRI or SDD. Since the studies have been published at different times, we first converted the cost estimates reported by individual studies into inflation-corrected 2018 United States dollar (US\$) values using the medical consumer price index [44, 45]. If a study reported the inflation-corrected year for cost estimates, then the 2018 US\$ value was obtained by appropriate correction to the reported year. Otherwise, midpoint of the data collection period was used as the proxy year for the cost estimates and the inflation correction was applied to this proxy year.

For meta-analytic synthesis, we used Hedges' summary estimate (g) [46] in a random effects framework of the DerSimonian and Laird model [47]. Inverse variance weights were used to compute the summary estimates. Heterogeneity was

quantified using the I^2 statistic [48]. Sources of heterogeneity were investigated using two approaches: first, we constructed the Baujat plots [49] to investigate the simultaneous influence of each study on summary estimate and heterogeneity. Second, we used meta-regression in an univariable fashion to estimate the I^2 explained by putative confounders. Statistical analyses were conducted using the metan software package [50] under STATA 12.0 (College Station, Texas). Statistical significance was tested at a type 1 error rate of 0.05.

3. Results

3.1 Costs of TRI versus TFI in the United States

3.1.1 Initial economic studies related to TRI versus TFI

In 1996, Mann *et al.* [51] published the first cost-effectiveness study of TRI. The primary outcome in this study was the hospital charge of TRI as compared to TFI and it was found that in a randomized, controlled setting of 152 PCIs, the hospital charge for TRI procedures was significantly lower than that for TFI (\$14,374 versus \$15,796) [51]. The same group of investigators published another randomized trial of ACS patients in 1998 and reported that the TRI approach was associated with lower hospital charges as compared to TFI (\$20,476 versus \$23,389) in ACS patients also [52]. For over a decade after these initial reports, economic evaluation of TRI was not undertaken in the United States. Much of the focus during this time was on demonstrating that the complications and outcomes of TRI versus TFI are either comparable or improved.

Table 1. Characteristics of the studies included in the meta-analysis.

Study	Year	Type of study	N	Patient source	Prevalence of TRI	Cost period	Cost of TRI/SDD		Cost of TFI/NSDD		Inclusion/Exclusion	Study period	Dollar year	Cost reduction		2018 cost reduction	
							Mean	SD	Mean	SD				Mean	SD	Mean	SD
Studies on cost saving of TRI																	
Applegate <i>et al.</i>	2013	Observational	1,140	Wake Forest Baptist Medical Center, Winston-Salem, NC	0.5	Hospitalization	15,186	4,803	15,918	5,234	PCIs after Sep 2009, elective only, no STEMI, no CABG, propensity matching	Jan. 2009–Dec. 2011	2010	732	288	914	360
Safley <i>et al.</i>	2013	Observational	61,509	Premier Healthcare Database	0.0909	Hospitalization	11,736	268	12,288	393	All patients, single PCI, single stent, no CS, no data on MI status	2004–2009	2012	552	254	645	297
Amin <i>et al.</i>	2013	Observational	7,121	NCDR (5 hospitals)	0.1712	Hospitalization	14,954	204	15,784	161	PCIs at study centers, single PCI, no CS, no CTO	Jan. 2010–Mar. 2011	2011	830	267	1,006	324
Amin <i>et al.</i>	2017	Observational	279,987	Medicare beneficiaries	0.0904	Hospitalization	15,786	72	16,701	41	All matching claims, no ACS, no CTO, no CS, no CA	Jul. 2009–Dec. 2012	2014	915	71	1,020	79
Studies on cost saving of SDD																	
Amin <i>et al.</i>	2017	Observational	279,987	Medicare beneficiaries	0.0529	Hospitalization	13,256	83	16,753	40	All matching claims, no ACS, no CTO, no CS, no CA	Jul. 2009–Dec. 2012	2014	3,502	78	3,902	86
Amin <i>et al.</i>	2018	Observational	672,470	Premier Healthcare Database	0.0906	Hospitalization			Not reported		Elective PCIs	Jan. 2006–Dec. 2015	2016	5,128	61	5,364	64
Amin <i>et al.</i>	2018	Observational	1,752	Single center NCDR CathPCI data	0.1312	Hospitalization			Not reported		Elective PCIs	Jul. 2009–Sept. 2015	2016	7,331	1,481	7,668	1,549
Rodriguez-Araujo <i>et al.</i>	2018	Observational	490	Single center registry	0.5	30 days	4,493	119	7,112	267	Elective, transradial PCIs from RASSADA PCI trial		2018	2,619	293	2,621	293
Kwok <i>et al.</i>	2019	Observational	324,345	NRD repository	0.0157	30 days	15,063	109	16,968	34	Elective PCIs, no MCS, no CS, no CABG	2010–2014	2012	1,905	114	2,227	133
Rymer <i>et al.</i>	2019	Observational	2,184	VA CART repository	0.33	30 days	23,656	574	25,878	458	First, unstaged, elective PCI, no weekend adm, no urgent or salvage procedures, no in-lab complications	Oct. 2008–Sep. 2016	2016	1,503	383	1,572	400

3.1.2 Recent economic studies of TRI versus TFI

A prior meta-analysis [24] published in 2012 on the heels of an earlier meta-analytic cost-benefit analysis [53] has detailed the economic benefits of TRI over TFI. For example, it has been shown that the lower complication rates and shorter hemostasis time associated with radial access are sufficient to offset the comparable (or potentially longer) procedural time and higher crossover rates such that there is a net estimated direct cost saving of \$275 per patient [53]. This estimate was reflective of the costs saved by way of reduced complications which are costly in the context of PCI [53].

A year after this meta-analysis was published, Safley *et al.* [54] used a propensity-matched analysis from a large, nationally representative repository and estimated the per-patient saving of \$533 attributable to TRI. The cost savings associated with TRI in this study, primarily stemmed from a reduced post-PCI length of stay among TRI patients. Notably, the cost savings were directly proportional to the estimated bleeding risk such that in patients with high predicted probability of bleeding there could be a \$1046 cost saving with TRI. Since this study, this group of investigators has published two additional studies based on patients in the NCDR registry (5 hospitals, $n = 7,121$) and Medicare beneficiaries ($n = 279,987$) which have again showed statistically significant cost savings associated with TRI [36, 55]. One of these two studies [36], also demonstrated a corroborating finding that cost savings attributable to TRI can be greater in patients with a high predicted risk of bleeding (\$1,621).

3.1.3 Meta-analysis of US studies on the cost savings of TRI

Fig. 2A shows a forest plot of the four US studies on TRI-related cost savings that were included in meta-analyses. Table 1 shows that these studies came from widely varying patient sources—single center, Premier Healthcare database, NCDR CathPCI for 5 hospitals and Medicare beneficiaries. These studies generally reported a consistent and significant cost saving associated with TRI that ranged from US\$ 553–US\$ 916 per PCI. After accounting for currency inflation, the results from random-effects meta-analysis showed that the estimated, average, adjusted cost savings attributable to TRI in 2018 were US\$ 992.30 (95% CI 850.36–1134.23). Also, despite varying sources of patient information and largely varying sample sizes, these studies were still statistically homogeneous ($I^2 = 0$, $P 0.674$) indicating that the summary estimate of cost saving obtained from the meta-analysis was reliable. This homogeneity is evident also from the Baujat plot (Fig. 2B). As shown in the Baujat plot, the overall Q statistic of 1.54 was largely contributed by one study [54] that did not impact the summary estimate of cost saving while the remaining three studies did not contribute to heterogeneity substantially.

3.1.4 Corroborating evidence from around the world

Table 2 shows the evidence for significant cost savings associated with TRI use as reported by studies around the

world. There have been 7 published studies [15, 56–61] that have reported cost differential in TRI and TFI-3 studies from China [58–60] and 1 each from France [56], Mexico [57], Poland [15] and England [61]. Irrespective of the country where from a study was reported, there was a consistent observation of a reduced cost associated with TRI. For international cost savings, the international currency conversion rates, varying payment systems, and different publication years of these studies make it difficult to arrive at a standardized estimate of cost saving that is comparable across the datasets but the consistency of derived estimates of cost savings in these studies is evident. Data presented in these studies again demonstrate reduced rates of complications as the primary driver rather than procedural cost differences. For example, in a small trial, Dziki *et al.* [62] demonstrated comparable procedural cath lab costs when comparing TRI to TFI. Finally, it is noteworthy that the recent, large study [61] from England again demonstrated that the TRI costs are even lower in STEMI patients (348£) as compared to stable CAD patients (153£)—a finding that is concordant with the Safley *et al.* [54] and Amin *et al.* [55] studies from the US implying that the cost savings tend to be higher in high-risk patients. Together these studies corroborate the results of meta-analysis of the US studies presented in Fig. 2A.

3.2 Economic benefits of Same-day discharge after PCI

3.2.1 SDD in eligible patients is safe and effective

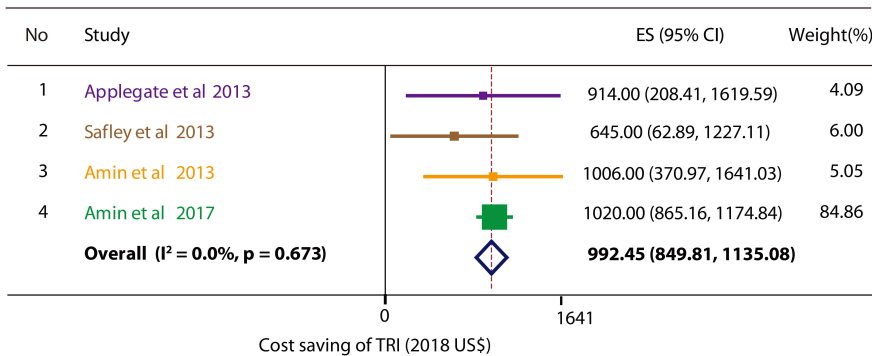
Abedlaal *et al.* [28] published a meta-analysis of randomized controlled trials (RCTs) and observational studies that demonstrated similar clinical outcomes for SDD versus overnight stay. Another meta-analysis [63], published in 2017 also demonstrated similar findings. In a recently published meta-analysis of 11 studies with 21,687 patients, Lu *et al.* [64] have demonstrated that early and late clinical outcomes in patients discharged on the same day of PCI were comparable to those discharged after an overnight stay. While the clinical value of SDD is thus clearly established [65], the subsequent reductions in costs of PCI have not been systematically studied and are not clearly established.

3.2.2 Meta-analysis of US studies on cost savings of SDD

Six studies [32, 33, 36, 41, 66, 67], were eligible for meta-analysis of the cost savings of SDD in the US. Notably, these studies represent research published in the last three years (2017–2019). All the included studies were observational in nature with prevalence of SDD varying widely from 1.6% to 50% (two studies represented a matched comparison of SDD versus NSDD in a 1 : 1 or 1 : 2 proportion). Three studies [36, 41, 66] reported costs over the duration of hospitalization while the other three studies [32, 33, 67] reported cumulative 30-days costs. The reported mean adjusted per-PCI cost savings in these studies ranged from US\$ 1,503 to US\$ 7,331.

After inflation-correcting to year 2018 and using the random effects meta-analytic framework, we estimated that the mean per-PCI cost savings of SDD were US\$ 3,567.58 (95%

A



B

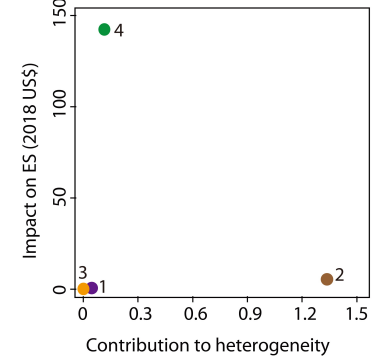


Fig. 2. Meta-analysis of the cost savings of TRI. (A) Forest plot of the published studies. Each study is color-coded. Boxes are proportional to the inverse-variance weights; error bars indicate 95% confidence intervals. Diamond represents the summary effect size. (B) Boujat plot for the studies included in meta-analysis. Studies are color-coded and numbered to match the scheme in panel A.

Table 2. Studies on cost savings of TRI from around the world.

Study	Year	Type of study	N	Country	Prevalence of TRI	Inclusion/Exclusion	Cost reduction	Currency
CARAFE	2001	RCT	210	France	0.66	All PCIs, no MI, no CABG, no RHC	586.5	€
Escárcega <i>et al.</i>	2010	Observational	174	Mexico		131 stable coronary patients, 43 ACS patients	509.0	\$
Jin <i>et al.</i>	2016	Observational	5,306	China	0.885	Single center, single PCI, no CS, no CTO, no IABP	8,081.0	¥
Koltowski <i>et al.</i>	2016	RCT	103	Poland	0.5	STEMI patients from OCEAN RACE trial	314.0	€
Jin <i>et al.</i>	2017	Observational	1,229	China		Elderly patients	7,495.0	¥
Jin <i>et al.</i>	2017	Observational	1,392	China		Women only	7,474.0	¥
Mamas <i>et al.</i>	2018	Observational	248,228	England	0.5	All indications	250.6	£
		Observational	94,856	England	0.5	Elective/Stable CAD only	153.9	£
		Observational	87,904	England	0.5	NSTEMI/UA only	282.2	£
		Observational	65,468	England	0.5	STEMI only	348.3	£

CI US\$ 2,303.39–US\$ 4,831.78, Fig. 3A). However, there was a highly significant heterogeneity in the cost savings estimates across the studies ($I^2 = 99.2\%$, $P < 0.001$). We therefore investigated the source of this heterogeneity using Baujat plot (Fig. 3B). We found that the heterogeneity Q statistic of 617.56 was mainly contributed to by two studies [41, 67] (combined contribution = 79% of overall heterogeneity). Both these studies have large sample sizes and narrow confidence intervals around the estimated cost saving and, as a result, contributed to the overall heterogeneity (Fig. 3B). Of these two however, one study [67] did not have a substantial impact on the summary effect size. When we conducted subgroup meta-analyses based on whether the studies reported hospitalization costs or 30-day cumulative costs, we found that the summary estimate of cost saving was higher for hospitalization costs than that for the 30-day costs (US\$ 5,042 versus US\$ 2,208). In the subgroup analyses, significant heterogeneity remained for the hospitalization cost studies ($I^2 = 98.9\%$, $P < 0.001$) but not for the 30-day cost studies ($I^2 = 55.4\%$, $P = 0.106$, Fig. 3A).

Using univariable meta-regression we also investigated the potential contribution of cost period, prevalence of SDD, prevalence of TRI, average age, proportion of females and the proportion of elective PCIs on heterogeneity. We found that only cost period (hospitalization costs versus 30-day costs)

reached statistical significance ($P = 0.029$) whereas none of the remaining putative predictors could adequately explain between-study heterogeneity.

3.2.3 Combined influence of TRI and SDD on cost savings

Marso and Amin *et al.* [68] had conjectured that a combination of TRI and SDD could be highly desirable. The Amin *et al.* [36] study first demonstrated that the cost saving in patients who underwent TRI and SDD as compared to those who underwent TRI and NSDD was US\$ 3,689 (95% CI US\$ 3,486–US\$ 3,902)—largest in all pairwise comparisons based on access site and SDD. Next largest cost saving was in patients who underwent TRI and were compared based on whether or not they were discharged same day. The cost saving in TRI-SDD patients was US\$ 3,035 (95% CI US\$ 2,825–US\$ 3,273) when compared with TRI-NSDD patients. This comparison is similar to the Rodriguez-Araujo study [33] which only included transradially accessed elective PCIs and reported a cost reduction of US\$ 2,619 (95% CI US\$2,033–US\$ 3,204). While the small number of studies reporting cost saving of SDD in the context of TRI and the heterogeneity in the reference groups used for estimating the cost savings preclude a formal meta-analysis, these observations point towards substantial cost savings by combining TRI and SDD.

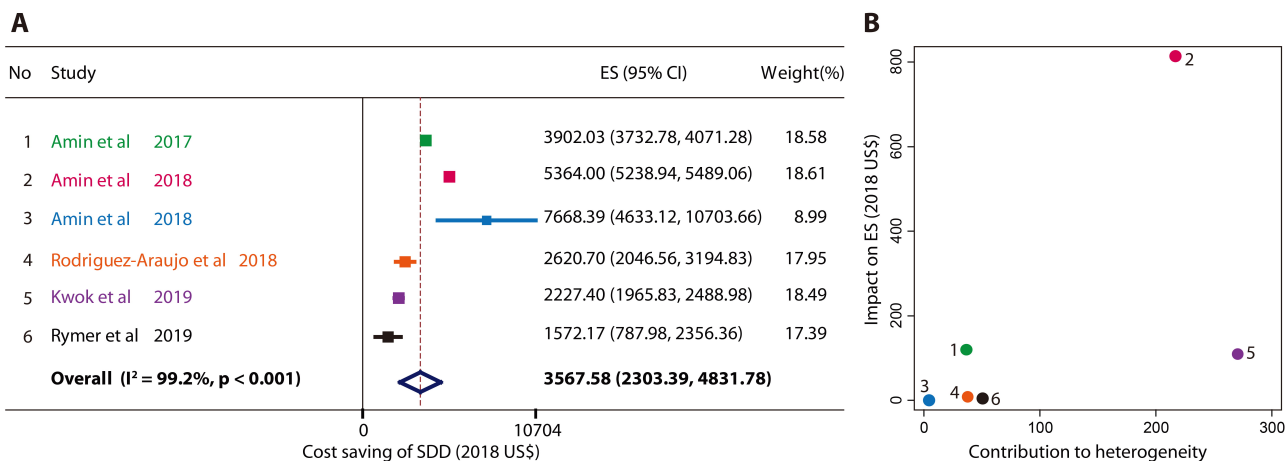


Fig. 3. Meta-analysis of the cost savings of SDD. (A) Forest plot of the published studies. Each study is color-coded. Boxes are proportional to the inverse-variance weights; error bars indicate 95% confidence intervals. Diamonds indicate the group-specific and overall summary effect size. (B) Boujat plot for the studies included in meta-analysis. Studies are color-coded and numbered to match the scheme in panel A.

3.2.4 Supportive evidence for SDD-based cost savings from around the world

A randomized controlled trial of SDD (the EPOS trial) in TFI patients from The Netherlands (2007) first reported a cost saving of US\$ 258 attributable to SDD [69]. Later, economic analyses of the patients enrolled in the Canadian EASY clinical trial showed that there was a per patient saving of \$1,141 when SDD was resorted to [43]. In 2013, a French study showed a cost saving of €1,074 attributable to ambulatory discharge as compared to conventional PCI [70]. A study from Ontario, Canada found that SDD PCI costs roughly 1,200 Canadian Dollars less than NSDD PCI [29]. These international studies from various countries together lend further support in favor of a consistent cost saving associated with SDD.

4. Discussion

To our knowledge, this is the first systematic review and meta-analyses of the cost savings associated with TRI and SDD in PCI. Our report makes the following key observations: first, the cost savings of TRI from four US studies of 349,757 patients were US\$ 992 and the cost savings of SDD from six US studies of 1,281,228 patients were US\$ 3,568; second, while the reported estimates of cost savings of SDD have been higher than that of TRI, more homogeneous studies are needed before a reliable estimate of SDD cost savings can be obtained; third, a combination of TRI and SDD is likely to yield significant cost savings for patients undergoing PCI; and lastly, all of these inferences are consistently supported by numerous trials and registries.

According to the Institute of Medicine, an ideal healthcare system should provide care that is safe, effective, efficient, equitable, timely and patient-centered [71]. In this context, the appropriateness of both TRI and SDD as candidate approaches to PCI care is self-evident. Both approaches are safe (as shown by several previous studies and meta-analyses)

[33, 72–75] effective as demonstrated by the associated cost savings shown here; efficient (as demonstrated by studies on time demands of PCI options) [43, 76–78] and patient-centered (since they both target patient satisfaction) [66]. In this context, it is encouraging to note that the use of TRI in the United States is rapidly increasing. The NCDR CathPCI Registry showed that in 2014 that the prevalence of TRI had risen to 25% of all PCIs while the VA-CART Registry showed a prevalence of 32% of TRI in 2018 [79–81]. However, even today most of the patients still undergo TFI. Assuming a total of 900,000 PCIs nationally, even if the TRI rate were to increase modestly from 30% to 50%, then we estimate a national cost saving of 178.5 million US\$ annually. As indicated by the studies in this review, this estimate is likely to be even higher (although restricted to elective PCIs only) by increasing use of SDD. Lu *et al.* [64] state that 57% of the interventionalists in the US practice SDD. These practice trends (switching over to the TRI/SDD pathway) need to therefore continue and be bolstered.

The size of both the meta-analyses presented here also points towards a need for more studies in this domain. However, a glaring finding from our analyses is the paucity of randomized, controlled studies on the cost savings of both TRI and SDD (especially the latter). Most of the data that currently exists comes from observational studies. Whereas these observational studies have provided key insights into the econometrics of PCI, measured or unmeasured confounding can remain even if all the studies have rigorously adjusted for as many confounders as possible [82, 83]. In the future, large-scale multicenter randomized studies evaluating the costs of various care pathways (e.g., TRI/SDD) could provide a robust estimate of financial effects of these interventions. Combining TRI and SDD pathways is logical since, as shown by Koutouzis *et al.* [84], the main driver of SDD is TRI. These studies are essential for wide-ranging practice changes in the direction of TRI and SDD. Certainly, guide-

lines such as the 2021 ACC Expert Consensus Decision Pathway on Same-Day Discharge After Percutaneous Coronary Intervention by Rao *et al.* [85], also help increase the utilization of SDD after TRI.

While attempting to increase TRI in higher risk populations, one needs to bear in mind the risk of cross-over. In the MATRIX (Minimizing Adverse Haemorrhagic Events by Transradial Access Site and Systemic Implementation of Angiox)-Access trial (NCT01433627) of 8404 patients with acute coronary syndrome who were randomized to radial or femoral access, access-site crossover from radial to femoral occurred in 183 of 4197 patients (4.4%). Crossing over from radial to femoral access abolished the bleeding benefit offered by the radial, where a ~2-fold higher rate of Bleeding Academic Research Consortium type (BARC) 3 or 5 bleeding was found among the femoral cross-over patients [86]. Thus, access site crossover occurs in a non-negligible proportion of patients undergoing PCI and may have a potential impact on clinical outcomes, costs, and time to discharge [86]. Whether vascular closure devices (VCDs) may reduce femoral artery complications is debated [87], and whether their use can narrow the gap in outcomes between radial and femoral access outcomes remains unclear [88]. In the same MATRIX trial, 30-day access site-related complications were evaluated between femoral access with VCDs, without VCDs and radial access [86]. They found the use of VCD does not reduce the risks of access site complications as compared with manual compression [86]. Access site complications with femoral access with or without the use of VCDs were equally high when compared with radial access [86]. Thus, VCDs did not mitigate the risk of access site complications and do not support the hypothesis that routine use of VCDs may narrow the gap between radial and femoral access. Lastly, evaluating the reasons for heterogeneity in studies related to SDD cost savings are limited in this meta-analysis due to a small number of studies. Although the duration of cost ascertainment (hospitalization versus 30-day costs) reached statistical significance and may be a contributor of the observed heterogeneity, it did not fully explain the residual heterogeneity. Other study characteristics such as age distribution, gender representation and TRI prevalence did not significantly contribute to the between-study heterogeneity. Thus, it appears that costs savings achieved due to SDD are consistent across patient characteristics such as age and gender and even TRI prevalence, but differ by the duration of cost ascertainment (hospitalization versus 30-day costs). As more studies on SDD accumulate, it may be possible to more comprehensively evaluate heterogeneity in the future.

5. Conclusions

There is adequate evidence to indicate that TRI can reduce hospitalization costs of PCI by approximately US\$ 1,000 per patient. Published studies indicate that cost savings of SDD are likely to be even higher but substantial heterogeneity exists in estimates of cost savings across studies. More

robust data from controlled trials are needed to reliably establish SDD cost savings.

Author contributions

HR and AA conceived and designed the study; HR performed the analysis; HR and AA interpreted the analysis; HR and AA wrote the paper; MT, JD, ER, MY and SL contributed to the manuscript revisions.

Ethics approval and consent to participate

The institutional review board of the Washington University of St. Louis, MO approved the project and deemed it 'not human subjects research', exempt from informed consent. The IRB approval number is: IRB ID #: 201804060.

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Conflict of interest

Dr. Amit P. Amin—has been funded via a comparative effectiveness research KM1 career development award from the Clinical and Translational Science Award (CTSA) program of the National Center for Advancing Translational Sciences of the National Institutes of Health, Grant Numbers UL1TR000448, KL2TR000450, TL1TR000449 and the National Cancer Institute of the National Institutes of Health, Grant Number 1KM1CA156708-01; an AHRQ R18 grant award (Grant Number R18HS0224181-01A1), an unrestricted grant from Terumo and is a consultant to Terumo.

No sponsor participated in the design and conduct of the study, collection, analysis, or interpretation of the data, nor in the preparation, review, nor approval of the manuscript. Drs. Amin and Kulkarni had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

References

- [1] Elgharib NZ, Shah UH, Coppola JT. Transradial cardiac catheterization and percutaneous coronary intervention: a review. *Coronary Artery Disease*. 2009; 20: 487–493.
- [2] Pillay D, Lam KH, Muda MN, Hamid Z. Transradial coronary angioplasty and stenting—immediate results and 3-month clinical follow-up in the first 50 patients performed at the National Heart Institute. *The Medical Journal of Malaysia*. 2000; 55: 467–472.
- [3] Campeau L. Percutaneous radial artery approach for coronary angiography. *Catheterization and Cardiovascular Diagnosis*. 1989; 16: 3–7.
- [4] Kiemeneij F, Laarman GJ, Odekerken D, Slagboom T, van der Wieken R. A randomized comparison of percutaneous transluminal coronary angioplasty by the radial, brachial and femoral approaches: the access study. *Journal of the American College of Cardiology*. 1997; 29: 1269–1275.
- [5] Kiemeneij F, Laarman GJ, Slagboom T, van der Wieken R. Outpa-

- tient coronary stent implantation. *Journal of the American College of Cardiology*. 1997; 29: 323–327.
- [6] Kiemeneij F, Laarman GJ. Percutaneous transradial artery approach for coronary Palmaz-Schatz stent implantation. *American Heart Journal*. 1994; 128: 167–174.
 - [7] Kiemeneij F, Laarman GJ. Percutaneous transradial artery approach for coronary stent implantation. *Catheterization and Cardiovascular Diagnosis*. 1993; 30: 173–178.
 - [8] Khan AA, Panchal HB, Zaidi SIM, Papireddy MR, Mukherjee D, Cohen MG, *et al*. Safety and efficacy of radial versus femoral access for rotational Atherectomy: a systematic review and meta-analysis. *Cardiovascular Revascularization Medicine*. 2019; 20: 241–247.
 - [9] Hinohara TT, Rao SV. Current state of radial artery catheterization in ST-elevation myocardial infarction. *Progress in Cardiovascular Diseases*. 2015; 58: 241–246.
 - [10] Rao SV, Bernat I, Bertrand OF. Clinical update: remaining challenges and opportunities for improvement in percutaneous transradial coronary procedures. *European Heart Journal*. 2012; 33: 2521–2526.
 - [11] Rao SV, Cohen MG, Kandzari DE, Bertrand OF, Gilchrist IC. The transradial approach to percutaneous coronary intervention. *Journal of the American College of Cardiology*. 2010; 55: 2187–2195.
 - [12] Ye Y, Zeng Y. Comparison between radial and femoral access for percutaneous coronary intervention in left main coronary artery disease. *Coronary Artery Disease*. 2019; 30: 79–86.
 - [13] Lee MH, Bang DW, Park BW, Cho B, Rha S, Jeong MH, *et al*. Transradial versus transfemoral intervention in non-ST-segment elevation acute coronary syndrome patients undergoing percutaneous coronary intervention: the Korean transradial intervention registry of 1 285 patients. *Cardiovascular Journal of Africa*. 2018; 29: 374–380.
 - [14] Xu Y, Jin C, Qiao S, Wu Y, Yan H, Dou K, *et al*. A comparison of transradial and transfemoral percutaneous coronary intervention in chinese women based on a propensity score analysis. *Korean Circulation Journal*. 2018; 48: 719–727.
 - [15] Koltowski L, Filipiak KJ, Kochman J, Pietrasik A, Huczek Z, Balsam P, *et al*. Cost-effectiveness of radial vs. femoral approach in primary percutaneous coronary intervention in STEMI-Randomized, control trial. *Hellenic Journal of Cardiology*. 2016; 57: 198–202.
 - [16] Pang J, Zhang Z, Yang Y, Li N, Bai M, Peng Y, *et al*. The efficacy and safety of transradial percutaneous coronary intervention VS transfemoral percutaneous coronary intervention for ST-segment elevation myocardial infarction patients: a meta-analysis. *International Journal of Cardiology*. 2014; 177: 483–488.
 - [17] Piccolo R, Galasso G, Capuano E, De Luca S, Esposito G, Trimarco B, *et al*. Transradial versus transfemoral approach in patients undergoing percutaneous coronary intervention for acute coronary syndrome. A meta-analysis and trial sequential analysis of randomized controlled trials. *PloS one*. 2014; 9: e96127.
 - [18] Dou K, Xu B, Yang Y, Chen J, Qiao S, Wang Y, *et al*. Comparison of procedural and long-term outcomes between transradial and transfemoral approach in one-stage intervention for triple vessel coronary artery disease. *Journal of Interventional Cardiology*. 2014; 27: 108–116.
 - [19] Qin X, Xiong W, Wang L, Guan E, Lu C. Clinical investigation of transradial access for emergent percutaneous coronary intervention in patients with acute myocardial infarction. *Clinical Interventions in Aging*. 2013; 8: 1139–1142.
 - [20] Numasawa Y, Kohsaka S, Miyata H, Kawamura A, Noma S, Suzuki M, *et al*. Safety of transradial approach for percutaneous coronary intervention in relation to body mass index: a report from a Japanese multicenter registry. *Cardiovascular Intervention and Therapeutics*. 2013; 28: 148–156.
 - [21] Yang YJ, Kandzari DE, Gao Z, Xu B, Chen JL, Qiao SB, *et al*. Transradial versus transfemoral method of percutaneous coronary revascularization for unprotected left main coronary artery disease: comparison of procedural and late-term outcomes. *JACC: Cardiovascular Interventions*. 2010; 3: 1035–1042.
 - [22] Eichhöfer J, Horlick E, Ivanov J, Seidelin PH, Ross JR, Ing D, *et al*. Decreased complication rates using the transradial compared to the transfemoral approach in percutaneous coronary intervention in the era of routine stenting and glycoprotein platelet IIB/IIIA inhibitor use: a large single-center experience. *American Heart Journal*. 2008; 156: 864–870.
 - [23] Valsecchi O, Musumeci G, Vassileva A, Tespili M, Guagliumi G, Gavazzi A, *et al*. Safety, feasibility and efficacy of transradial primary angioplasty in patients with acute myocardial infarction. *Italian Heart Journal*. 2003; 4: 329–334.
 - [24] Mason PJ, Shah B, Tamis-Holland JE, Bittl JA, Cohen MG, Safirstein J, *et al*. An update on radial artery access and best practices for transradial coronary angiography and intervention in acute coronary syndrome: a scientific statement from the American Heart Association. *Circulation: Cardiovascular Interventions*. 2018; 11: e000035.
 - [25] Chambers CE, Dehmer GJ, Cox DA, Harrington RA, Babb JD, Popma JJ, *et al*. Defining the length of stay following percutaneous coronary intervention: an expert consensus document from the Society for Cardiovascular Angiography and Interventions. Endorsed by the American College of Cardiology Foundation. *Catheterization and Cardiovascular Interventions*. 2009; 73: 847–858.
 - [26] Giustino G, Cota L, Chieffo A. Targeting transradial approach. *Panminerva Medica*. 2015; 57: 29–42.
 - [27] Gilchrist IC. Same day discharge after elective percutaneous coronary intervention. *Current Cardiology Reports*. 2014; 16: 470.
 - [28] Abdelaal E, Rao SV, Gilchrist IC, Bernat I, Shroff A, Caputo R, *et al*. Same-day discharge compared with overnight hospitalization after uncomplicated percutaneous coronary intervention: a systematic review and meta-analysis. *JACC: Cardiovascular Interventions*. 2013; 6: 99–112.
 - [29] Madan M, Bagai A, Overgaard CB, Fang J, Koh M, Cantor WJ, *et al*. Same-day discharge after elective percutaneous coronary interventions in Ontario, Canada. *Journal of the American Heart Association*. 2019; 8: e012131.
 - [30] Din JN, Snow TM, Rao SV, Klinke WP, Nadra JJ, Della Siega A, *et al*. Variation in practice and concordance with guideline criteria for length of stay after elective percutaneous coronary intervention. *Catheterization and Cardiovascular Interventions*. 2017; 90: 715–722.
 - [31] Rao SV, Kaltenbach LA, Weintraub WS, Roe MT, Brindis RG, Rumsfeld JS, *et al*. Prevalence and outcomes of same-day discharge after elective percutaneous coronary intervention among older patients. *The Journal of the American Medical Association*. 2011; 306: 1461–1467.
 - [32] Rymer JA, O'Donnell CI, Plomondon ME, Hess PL, Donahue M, Hebert L, *et al*. Same-day discharge among patients undergoing elective PCI: insights from the VA CART Program. *American Heart Journal*. 2019; 218: 75–83.
 - [33] Rodriguez-Araujo G, Cilingiroglu M, Mego D, Hakeem A, Lendel V, Cawich I, *et al*. Same versus next day discharge after elective transradial PCI: the RADial same Day DischArge after PCI trial. *Cardiovascular Revascularization Medicine*. 2018; 19: 7–11.
 - [34] Seto AH, Shroff A, Abu-Fadel M, Blankenship JC, Boudoulas KD, Cigarroa JE, *et al*. Length of stay following percutaneous coronary intervention: an expert consensus document update from the society for cardiovascular angiography and interventions. *Catheterization and Cardiovascular Interventions*. 2018; 92: 717–731.
 - [35] Graziano FD, Banga S, Busman DK, Muthusamy P, Wohns DH. Barriers to early discharge after elective percutaneous coronary intervention (BED PCI): a single-center study. *Indian Heart Journal*. 2017; 69: 217–222.
 - [36] Amin AP, Patterson M, House JA, Giersiefen H, Spertus JA, Baklanov DV, *et al*. Costs associated with access site and same-day discharge among medicare beneficiaries undergoing percutaneous coronary intervention. *JACC: Cardiovascular Interventions*. 2017; 10: 342–351.

- [37] Komócsi A, Aradi D, Kehl D, Ungi I, Thury A, Pintér T, *et al.* Meta-analysis of randomized trials on access site selection for percutaneous coronary intervention in ST-segment elevation myocardial infarction. *Archives of Medical Science*. 2014; 10: 203–212.
- [38] Eleid MF, Rihal CS, Gulati R, Bell MR. Systematic use of transradial PCI in patients with ST-segment elevation myocardial infarction. *JACC: Cardiovascular Interventions*. 2013; 6: 1145–1148.
- [39] Nathan S, Rao SV. Radial versus femoral access for percutaneous coronary intervention: implications for vascular complications and bleeding. *Current Cardiology Reports*. 2012; 14: 502–509.
- [40] Bertrand OF, Larose E, De Larochellière R, Proulx G, Nguyen CM, Déry J, *et al.* Outpatient percutaneous coronary intervention: ready for prime time? *The Canadian Journal of Cardiology*. 2007; 23: 58B–66B.
- [41] Amin AP, Pinto D, House JA, Rao SV, Spertus JA, Cohen MG, *et al.* Association of same-day discharge after elective percutaneous coronary intervention in the united states with costs and outcomes. *JAMA Cardiology*. 2018; 3: 1041–1049.
- [42] Kiemeneij F, Hofland J, Laarman GJ, van der Elst DH, Lubbe HVD. Cost comparison between two modes of palmar schatz coronary stent implantation: transradial bare stent technique vs. transfemoral sheath-protected stent technique. *Catheterization and Cardiovascular Diagnosis*. 1995; 35: 301–308.
- [43] Rinfret S, Kennedy WA, Lachaine J, Lemay A, Rodés-Cabau J, Cohen DJ, *et al.* Economic impact of same-day home discharge after uncomplicated transradial percutaneous coronary intervention and bolus-only abciximab regimen. *JACC: Cardiovascular Interventions*. 2010; 3: 1011–1019.
- [44] Agency_for_Healthcare_Research_and_Quality. Using appropriate price indices for analysis of health care expenditures or income, across multiple years. 2019. Available at: https://meps.ahrq.gov/about_meps/Price_Index.shtml (Accessed: 25 November 2019).
- [45] Dunn A, Grosse SD, Zuvekas SH. Adjusting health expenditures for inflation: a review of measures for health services research in the United States. *Health Services Research*. 2018; 53: 175–196.
- [46] Rosenthal R, Rosnow RL. *Essentials of behavioral research: methods and data analysis*. New York: McGraw Hill. 1991.
- [47] DerSimonian R, Laird N. Meta-analysis in clinical trials. *Controlled Clinical Trials*. 1986; 7: 177–188.
- [48] Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *British Medical Journal*. 2003; 327: 557–560.
- [49] Baujat B, Mahé C, Pignon J, Hill C. A graphical method for exploring heterogeneity in meta-analyses: application to a meta-analysis of 65 trials. *Statistics in Medicine*. 2002; 21: 2641–2652.
- [50] Harris R, Bradburn M, Deeks J, Harbord R, Altman DG, Steichen T, *et al.* METAN: stata module for fixed and random effects meta-analysis. Statistical software components. Boston, MA: Boston College Department of Economics. 2006.
- [51] Mann, Cubeddu, Schneider, Arrowood. Right radial access for PTCA: a prospective study demonstrates reduced complications and hospital charges. *The Journal of Invasive Cardiology*. 1986; 8: 40D–44D.
- [52] Mann T, Cubeddu G, Bowen J, Schneider JE, Arrowood M, Newman WN, *et al.* Stenting in acute coronary syndromes: a comparison of radial versus femoral access sites. *Journal of the American College of Cardiology*. 1998; 32: 572–576.
- [53] Mitchell MD, Hong JA, Lee BY, Umscheid CA, Bartsch SM, Don CW. Systematic review and cost-benefit analysis of radial artery access for coronary angiography and intervention. *Circulation*. 2012; 5: 454–462.
- [54] Safley DM, Amin AP, House JA, Baklanov D, Mills R, Giersiefen H, *et al.* Comparison of costs between transradial and transfemoral percutaneous coronary intervention: a cohort analysis from the Premier research database. *American Heart Journal*. 2013; 165: 303–9.e2.
- [55] Amin AP, House JA, Safley DM, Chhatrwalla AK, Giersiefen H, Bremer A, *et al.* Costs of transradial percutaneous coronary intervention. *JACC: Cardiovascular Interventions*. 2013; 6: 827–834.
- [56] Louvard Y, Lefèvre T, Allain A, Morice M. Coronary angiography through the radial or the femoral approach: the CARAFE study. *Catheterization and Cardiovascular Interventions*. 2001; 52: 181–187.
- [57] Escárcega RO, Pérez-Alva JC, Jiménez-Hernández M, Mendoza-Pinto C, Pérez RS, Porras RS, *et al.* Transradial percutaneous coronary intervention without on-site cardiac surgery for stable coronary disease and myocardial infarction: preliminary report and initial experience in 174 patients. *The Israel Medical Association Journal*. 2010; 12: 592–597.
- [58] Jin C, Xu Y, Qiao S, Tang X, Wu Y, Yan H, *et al.* Comparison of transradial and transfemoral approaches in women undergoing percutaneous coronary intervention in China: a retrospective observational study. *Angiology*. 2017; 68: 799–806.
- [59] Jin C, Li W, Qiao S, Yang J, Wang Y, He P, *et al.* Costs and benefits associated with transradial versus transfemoral percutaneous coronary intervention in China. *Journal of the American Heart Association*. 2016; 5: e002684.
- [60] Jin C, Xu Y, Qiao S, Tang X, Wu Y, Yan H, *et al.* Transradial versus transfemoral approach for percutaneous coronary intervention in elderly patients in China: a retrospective analysis. *Chinese Medical Sciences Journal*. 2017; 32: 161–170.
- [61] Mamas MA, Tosh J, Hulme W, Hoskins N, Bungey G, Ludman P, *et al.* Health economic analysis of access site practice in England during changes in practice: insights from the British cardiovascular interventional society. *Circulation: Cardiovascular Quality and Outcomes*. 2018; 11: e004482.
- [62] Dziki B, Miechowicz I, Iwachów P, Kuzemczak M, Kałmucki P, Szyszka A, *et al.* Cath lab costs in patients undergoing percutaneous coronary angioplasty—detailed analysis of consecutive procedures. *Kardiologia Polska*. 2017; 75: 914–921.
- [63] Bundhun PK, Soogund MZS, Huang W. Same day discharge versus overnight stay in the hospital following percutaneous coronary intervention in patients with stable coronary artery disease: a systematic review and meta-analysis of randomized controlled trials. *PLoS ONE*. 2017; 12: e0169807.
- [64] Lu H, Guan W, Zhou Y, Bao H. Early versus late clinical outcomes following same day discharge after elective percutaneous coronary intervention: a systematic review and meta-analysis. *Medicine*. 2019; 98: e14025.
- [65] Shroff A, Kupfer J, Gilchrist IC, Caputo R, Speiser B, Bertrand OF, *et al.* Same-day discharge after percutaneous coronary intervention. *JAMA Cardiology*. 2016; 1: 216.
- [66] Amin AP, Crimmins-Reda P, Miller S, Rahn B, Caruso M, Pierce A, *et al.* Novel patient-centered approach to facilitate same-day discharge in patients undergoing elective percutaneous coronary intervention. *Journal of the American Heart Association*. 2018; 7: e005733.
- [67] Kwok CS, Rao SV, Gilchrist IC, Potts J, Nagaraja V, Gunning M, *et al.* Relation of length of stay to unplanned readmissions for patients who undergo elective percutaneous coronary intervention. *The American Journal of Cardiology*. 2019; 123: 33–43.
- [68] Abdelal E, Bertrand OF. Transradial PCI and same day discharge: a winning team? *Catheterization and Cardiovascular Interventions*. 2013; 81: 24–25.
- [69] Heyde GS, Koch KT, de Winter RJ, Dijkgraaf MGW, Klees MI, Dijkman LM, *et al.* Randomized trial comparing same-day discharge with overnight hospital stay after percutaneous coronary intervention: results of the Elective PCI in Outpatient Study (EPOS). *Circulation*. 2007; 115: 2299–2306.
- [70] Le Corvoisier P, Gellen B, Lesault P, Cohen R, Champagne S, Duval A, *et al.* Ambulatory transradial percutaneous coronary intervention: a safe, effective, and cost-saving strategy. *Catheterization and Cardiovascular Interventions*. 2013; 81: 15–23.
- [71] Institute of Medicine (US) Committee on Quality of Health Care in America. *Crossing the quality chasm: a new health system for the 21st century*. Washington, D.C.: National Academy Press. 2001.
- [72] Boudiche S, Mechri M, Ben Halima M, Rezik B, Khader N, Larbi

- N, *et al.* Feasibility and safety of same-day discharge after transradial percutaneous coronary intervention: a Tunisian monocentric study. *La Tunisie medicale*. 2019; 97: 650–658.
- [73] Brayton KM, Patel VG, Stave C, de Lemos JA, Kumbhani DJ. Same-day discharge after percutaneous coronary intervention: a meta-analysis. *Journal of the American College of Cardiology*. 2013; 62: 275–285.
- [74] Sarji R, Sricharoen N. Beyond the bend: a literature review and case report of radial artery loop. *The Journal of Invasive Cardiology*. 2011; 23: E271–272.
- [75] Chung W, Fang H, Tsai T, Yang C, Chen C, Chen S, *et al.* Transradial approach percutaneous coronary interventions in an outpatient clinic. *International Heart Journal*. 2010; 51: 371–376.
- [76] Aydin A, Gurol T, Soylu O, Dagdeviren B. Early ambulatory discharge is safe and feasible after transradial coronary interventions. *International Journal of Cardiology. Heart & Vessels*. 2014; 3: 60–63.
- [77] Gilchrist IC, Rhodes DA, Zimmerman HE. A single center experience with same-day transradial-PCI patients: a contrast with published guidelines. *Catheterization and Cardiovascular Interventions*. 2012; 79: 583–587.
- [78] Bertrand OF, Rodés-Cabau J, Larose E, Proulx G, Gleeton O, Nguyen CM, *et al.* Early and late outcomes in patients excluded from same-day home discharge after transradial stenting and maximal antiplatelet therapy. *Catheterization and Cardiovascular Interventions*. 2008; 72: 619–625.
- [79] Waldo SW, Gokhale M, O'Donnell CI, Plomondon ME, Valle JA, Armstrong EJ, *et al.* Temporal trends in coronary angiography and percutaneous coronary intervention: insights from the va clinical assessment, reporting, and tracking program. *JACC: Cardiovascular Interventions*. 2018; 11: 879–888.
- [80] Bradley SM, Rao SV, Curtis JP, Parzynski CS, Messenger JC, Daugherty SL, *et al.* Change in hospital-level use of transradial percutaneous coronary intervention and periprocedural outcomes: insights from the national cardiovascular data registry. *Circulation: Cardiovascular Quality and Outcomes*. 2014; 7: 550–559.
- [81] Hess CN, Peterson ED, Neely ML, Dai D, Hillegass WB, Krucoff MW, *et al.* The learning curve for transradial percutaneous coronary intervention among operators in the United States: a study from the national cardiovascular data registry. *Circulation*. 2014; 129: 2277–2286.
- [82] Ali MS, Prieto-Alhambra D, Lopes LC, Ramos D, Bispo N, Ichihara MY, *et al.* Propensity score methods in health technology assessment: principles, extended applications, and recent advances. *Frontiers in Pharmacology*. 2019; 10: 973.
- [83] Christenfeld NJS, Sloan RP, Carroll D, Greenland S. Risk factors, confounding, and the illusion of statistical control. *Psychosomatic Medicine*. 2004; 66: 868–875.
- [84] Koutouzis M, Agelaki M, Maniotis C, Dimitriou P, Tsoulmeleas A, Matsoukis I, *et al.* Predictors of same day discharge after percutaneous coronary interventions. *Cardiovascular Revascularization Medicine*. 2017; 18: 241–244.
- [85] Rao SV, Vidovich MI, Gilchrist IC, Gulati R, Gutierrez JA, Hess CN, *et al.* 2021 ACC expert consensus decision pathway on same-day discharge after percutaneous coronary intervention. *Journal of the American College of Cardiology*. 2021; 77: 811–825.
- [86] Gragnano F, Branca M, Frigoli E, Leonardi S, Vranckx P, Di Maio D, *et al.* Access-site crossover in patients with acute coronary syndrome undergoing invasive management. *JACC: Cardiovascular Interventions*. 2021; 14: 361–373.
- [87] Schulz-Schüpke S, Helde S, Gewalt S, Ibrahim T, Linhardt M, Haas K, *et al.* Comparison of vascular closure devices vs manual compression after femoral artery puncture. *Journal of the American Medical Association*. 2014; 312: 1981.
- [88] Rigattieri S, Sciahbasi A, Ratib K, Alonzo A, Cox N, Chodor P, *et al.* Comparison between radial approach and femoral approach with vascular closure devices on the occurrence of access-site complications and periprocedural bleeding after percutaneous coronary procedures: a systematic review and meta-analysis. *The Journal of invasive cardiology*. 2016; 28: 473–479.