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Original Article

Safety and feasibility of robotic assisted percutaneous coronary intervention compared to standard percutaneous coronary intervention- a systematic review and meta-analysis

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ABSTRACT

Objective: Robotically assisted PCI offers a great alternative to S–PCI. This has gained even more relevance during the COVID-19 pandemic era however safety of R–PCI compared to S–PCI has not been studied well. This study explores the safety and efficacy of robotically assisted PCI (R–PCI) compared to standard PCI (S–PCI) for the treatment of coronary artery disease (CAD).

Methods: PubMed, Scopus, Ovid, and Google scholar databases were searched for studies comparing R–PCI to S–PCI. Outcomes included clinical success, procedure time, fluoroscopy time, contrast use and radiation exposure.

Results: Theauthors included 5 studies comprising 1555 patients in this meta-analysis. Clinical success was comparable in both arms ($p = 0.91$). Procedure time was significantly longer in R–PCI group (risk ratio: 5.52, 95% confidence interval: 1.85 to 9.91, $p = 0.003$). Compared to S–PCI, patients in R–PCI group had lower contrast use (meandifference: −19.88, 95% confidence interval: −21.43 to −18.33, $p < 0.001$), fluoroscopy time (mean difference:-1.82, 95% confidence interval: −3.64 to −0.00, $p = 0.05$) and radiation exposure (mean difference:-457.8, 95% confidence interval: −707.14 to −208.14, $p < 0.001$).

Conclusion: R–PCI can achieve similar success as S–PCI at the expense of longer procedural times. However, radiation exposure and contrast exposure were lower in the R–PCI arm.

1. Introduction

Percutaneous coronary interventionis the dominant treatment strategy for patients with stable and unstable coronary artery disease. Occupational hazards are a prime concern for interventional cardiologists and cardiac catheterization laboratory (CCL) staff.[1–3] Orthopedic injury from the wear and tear of prolonged standing with lead aprons and stochastic and deterministic effects of radiation exposure are prime concerns. Robotic assisted PCI (R–PCI) is an emerging technology with promising results in mitigating the aforementioned occupational hazards to interventional cardiologists.[4] Reduced patient and CCL staff contact with a potentially COVID positive patient during coronary revascularization offers an advantage of R–PCI in this era. “Tele-stenting” is also a promising strategy whentime is a critical determinant of a successful outcome like during a STEMI or a stroke and access to coronary and neurointerventional specialists is limited.[5,6] Since the FDA approval of CorePath 200 robotic system (Corindus Vascular Robotics, Natick, Massachusetts) in 2012, only few studies and case reports have been published demonstrating efficacy of R–PCI in treating simple and complex coronary lesions.[4,7–10] Strong clinical data related to efficacy and safety of R–PCI is lacking and there are no randomized

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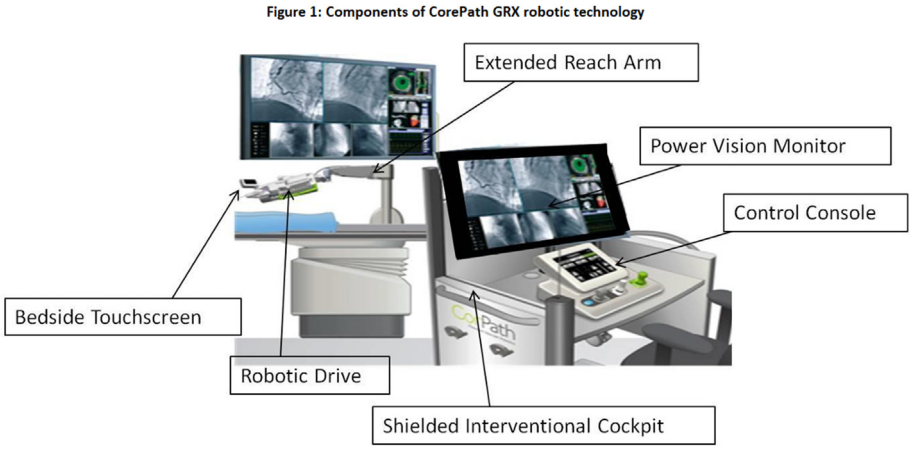

Fig. 1. Components of CorePath GRX robotic technology.

clinical trials (RCTs) available with currently available robotic platforms. The authors conducted a meta-analysis of all existing studies comparing R–PCI to S–PCI to bridge this gap in the literature.

1.1. Overview of current robotic technology

The parts of the current Corindus GX device are:

Remote controlled cockpit
An articulated robotic arm attached to the table
Disposable cassette to which the guide catheter is connected and through which the intravascular equipment is advanced and retracted.
Encompassed within the workspace are high-resolution angiographic and hemodynamic monitors, standard foot pedal controls, and a series of joysticks for control of the cassette's features (Fig. 1).

2. Methods

2.1. Study search and eligibility criteria

Two authors (B.T. and S.K.) independently and in duplicate searched PubMed, Scopus, Ovid and google scholar databases until the end of July 2020 to identify studies comparing R–PCI to S–PCI. A systematic search using the key words “Robotic PCI”, “Robotically assisted PCI” and “CorePath” was carried out. No search limitations by publication dates or language were set.

Studies that compared R–PCI to S–PCI for cardiac outcomes of interest were included in this metanalysis. Studies without any S–PCI comparison arm were excluded from this analysis.

2.2. Data extraction

We extracted the baseline characteristics and the treatment variables of the study population (Supplementary table 1), including the sample size of the studies, the design of the studies and exclusion criteria (Table 1). We also extracted the angiographic characteristics of the target lesions (Table 2).

2.3. Efficacy and safety outcomes

The efficacy outcomes of the analysis wereseparate end points of clinical success of the PCI and procedure time. Safety outcomes included separate endpoints contrast use, fluoroscopy time and radiation exposure.

2.4. Patient and public involvement

This study utilized results of already published studies to conduct the statistical analysis hence public and patient involvement is not applicable to this study. Additionally, this study was deemed exempt for IRB approval from University of Arizona ethics committee for the same reason.

Table 1
Characteristics of included studies.

	Smilowitz et al	Madder et al	Mahmud et al	Hirai et al	Patel et al
Year	2014	2016	2017	2019	2020
System used	CorePath 200	CorePath 200	CorePath 200	CorePath 200	CorePath GRX
R–PCI	40	45	108	49	310
S–PCI	80	168	126	46	686
Setting	Single center	Single center	Single center	Two centers	Single center
Randomization	No	No	No	No	No
Exclusion criteria	Ejection fraction <30% AMI within 72 h prior to procedure Recent complications from PCI within 30 days Planned PCI or CABG within 30 days	None	STEMI requiring primary PCI Requirement for over the wire devices Planned bifurcation stenting	Non-CTO >2 CTO lesion	Not available

R–PCI = Robotic assisted percutaneous coronary intervention; S–PCI= Standard percutaneous coronary intervention; AMI = Acute myocardial infarction; STEMI= ST Segment myocardial infarction; CTO= Chronic toral occlusion; CABG= Coronary artery bypass grafting.

Table 2
Angiographic characteristics of target lesion in included studies.

		Smilowitz et		Madder et al		Mahmud et al			Hirai et al		Patel et al	
		R–PCI	S–PCI	R–PCI	S–PCI	R–PCI	S–PCI	R–PCI	S–PCI	R–PCI	S–PCI	
Target Lesion (%)	LM	0	0	4.4	0.6	3.2	3.3	0	0	0.3	0.1	
	LAD	12.5	45	48.9	53.9	47.1	38.1	32.7	21.7	66.1	82.4	
	LCX + RI	30	27.5	28.9	18.6	21	39.3	14.3	37	15.8	5.7	
	RCA	57.5	27.5	24.4	35.3	27.4	32.7	53.1	41.3	16.1	10.1	
	Grafts	0	0	0	0	1.3	2.1	0	0	0.6	0.3	
Bifurcation lesion		0	0	NA	NA	NA	NA	12.2	28.3	1	1.5	
Chronic total occlusion		0	0	NA	NA	NA	NA	100	100	3.5	5.5	
Primary lesion stenosis (%)		76.9 ± 8.5	81.6 ± 9.2	NA	NA	84.9 ± 9.2	85.9 ± 9.8	100	100	NA	NA	
Primary lesion length (mm)		13.7 ± 4.8	13.9 ± 5.9	NA	NA	22.2 ± 10.6	19.4 ± 9.5	26.9 ± 18.6	20.1 ± 11.6	NA	NA	
SYNTAX Score		NA	NA	NA	NA	19.6 ± 13.0	15.7 ± 10.9	NA	NA	16 (10–23)	22 (16–28)	

R–PCI = Robotic assisted percutaneous coronary intervention; S–PCI= Standard percutaneous coronary intervention; LM = Left main coronary artery; LAD = Left anterior descending coronary artery; LCX = Left circumflex coronary artery; RI = Ramus intermedius branch; RCA = Right coronary artery; NA= Not available.

2.5. Statistical analysis

The statistical analysis was done in line with recommendations from the Cochrane Collaboration and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines using Review Manager (RevMan) version 5.1.7 (Copenhagen, Denmark, Nordic Cochrane Centre, The Cochrane Collaboration, 2012). Risk ratios for dichotomous outcomes and mean difference for continuous outcomes using random effect model were determined Heterogeneity was assessed using the I^2 statistic, defined as the proportion of total variation observed between the trials attributable to differences between trials rather than sampling error (chance), with values < 25% considered as low and >75% as high.[11] Analysis was performed on an intention-to-treat basis. We usedrandommodel. Publication bias was estimated visually by funnel plots, and/or using Begg's test and the weighted regression test of Egger[12](Supplementary figure 1).

All studies reported radiation exposure in mGy except Mahmoud et al who reported radiation exposure in $cGy.cm^2$ and hence excluded from the subgroup analysis to avoid the heterogeneity. Patel et al reported outcomes in median and interquartile range (IQR) and hence Hozo methodology[13] was applied to obtain mean and standard deviation for the purpose of meta-analysis.

3. Results

Our search strategy yielded 5 studies out of 44 articles initially screened.[14–18] We included 1535 patients in the final meta-analysis, with 552 patients receiving R–PCI and 983 patients treated with S–PCI(Fig. 2). Baseline characteristics of study population is provided in supplementary Table 1. Angiographic characteristics of target lesions in included studies is presented in Table 2.

Efficacy endpoint: Clinical success of R–PCI was found to be comparable to S–PCI (Risk ratio:1, 95% confidence interval: 0.98–1.02, p = 0.91) (Fig. 3A). Procedure time was significantly higher with R–PCI compared to S–PCI (mean difference:5.52,95% confidence interval: 1.85–9.19, p = 0.003) (Fig. 3B).

Safety endpoint: We noted an overall better safety profile with R–PCI compared to S–PCI. R–PCI was associated with lower use of contrast than S–PCI (mean difference: -19.88, 95% confidence interval: -21.43 to -18.33, p < 0.001) (Fig. 3C). Fluoroscopy time (Fig. 3D)was significantly lower with R–PCI compared to S–PCI arm (mean difference: −1.82 to −0.00, p = 0.05). Similarly, radiation exposure(Fig. 3E) was lesser among patients treated with R–PCI than S–PCI (mean difference: −457.8 to −208.5, p = 0.0003).

4. Discussion

The present study is themost up to date meta-analysis comparing efficacy and safety of R–PCI compared to S–PCI. The principal findings of this meta-analysis are – (1). Clinical efficacy and PCI success can be achieved with the same frequency as in S–PCI in a broad variety of lesion subsets including CTO's, bifurcations and in high risk subsets such as left main stenosis.[2] Procedure times were significantly longer with R–PCI compared to S–PCI.[3] R–PCI was associated with lower contrast use and lower fluoroscopy times and radiation dose to the patient.

Early in the experience with R–PCI such as in the PRECISE study[4] clinical success was achieved in 97.6% of lesions but the lesions treated were simple and there was no comparator arm. Single center studies have reported high clinical success rate with R–PCI in treating more complex lesions.[7,9] Technical iterations of the next generation device now allow for seating a guide catheter

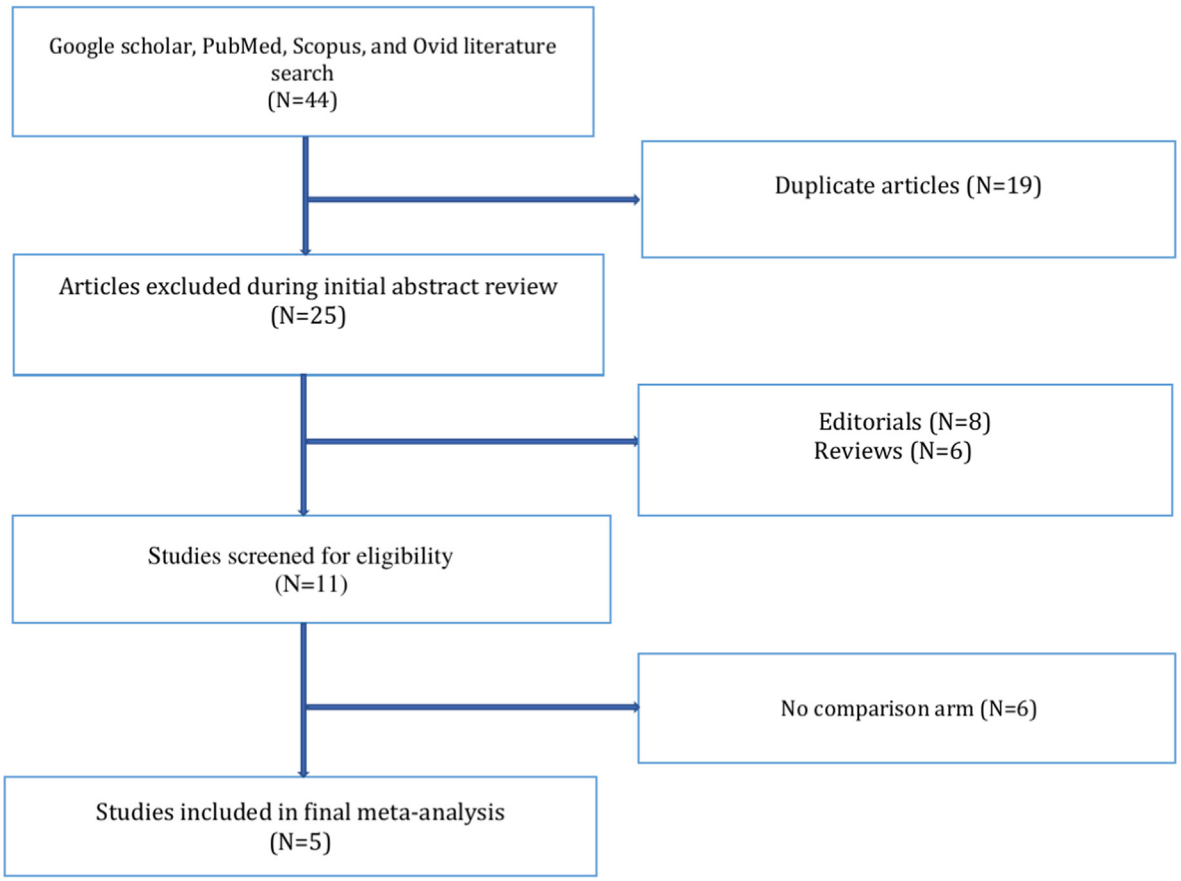

Fig. 2. Prisma diagram.

with a separate joystick. Intravascular imaging, laser atherectomy can be performed seamlessly and with the "retract and rotate" maneuver, side branches can also be wired. Due to the limitation of not being able to use "over the wire" systems with the current robot, manual crossover is needed to perform orbital and rotational atherectomy. For CTO PCI, the attractiveness of R–PCI is that radiation exposure to the PCI operator is reduced by almost 50%. After manual crossing of the CTO lesion, switching to R–PCI alleviates any further need for wearing a lead apron and almost eliminates further radiation exposure. R–PCI facilitates accurate stent placement by minimizing longitudinal geographic miss[8,19] which is quite common in S–PCI.[19]

Procedural time was higher with R–PCI than S–PCI. Higher procedure time with R–PCI is related to current limitations of the technology.[20] Current generation systems are not capable of performing vascular access and placement of sheaths and guiding catheters. Every change in balloon and stent requires manual placement of the device in the cassette. While this adds additional time to the case, it is noteworthy that this extra time is not additional radiation or fluoroscopy exposure to either patient or the interventional cardiologist. As operators and catheterization laboratory staff gain more experience with current generation devices this time will most certainly decrease.

Contrast volume, fluoroscopy time and radiation dose was significantly lower with R–PCI comparison to S–PCI. These benefits result from better visualization on the high definition monitors in the cockpit resulting in precise balloon and stent positioning and reduced chances of longitudinal geographic miss. There have been prior studies in which the number of stents used per case due to precise stent positioning has translated to cost savings.[19] A focused cost-effective analysis in a RCT would need to be performed before such claims can be validated.

Although this study did not compare long term outcomes of R–PCI and S–PCI there is no reason to believe that major adverse cardiovascular events (MACE) rates would be different at 1 year. Prior work by Walters et al[21] reported no difference in MACE in a study of 333 patients at 6 months and 12 months follow up.

R–PCI offers obvious advantages over S–PCI that cannot be measured tangibly in this meta-analysis or for that matter with any study. The bodies of interventional cardiologists over their lifespan are subjected to wear and tear from prolonged standing at the catheterization table with heavy lead shields. These lead aprons provide only partial protection from the ill effects of radiation exposure. The incidence of radiation exposure is higher on the left side and center of the cranium and in a cohort the incidence of brain and neck tumors amongst interventional cardiologists was disproportionately higher on the left side.[22,23] Fifty percent of interventional cardiologists report a job related orthopedic injury.[24] Wearing heavy lead aprons significantly contributes to these injuries. By reducing the time spent at the table and limiting the time wearing a lead apron, R–PCI significantly reduces the radiation exposure and risk of orthopedic injuries for the interventional cardiologist.

4.1. Limitations

This study has the following limitations.The lack of any RCT's comparing R–PCI with S–PCI limits the quality of the meta-analysis because the analysis is limited to observational data. This is a study-level and not a patient level meta-analysis. Differences in the

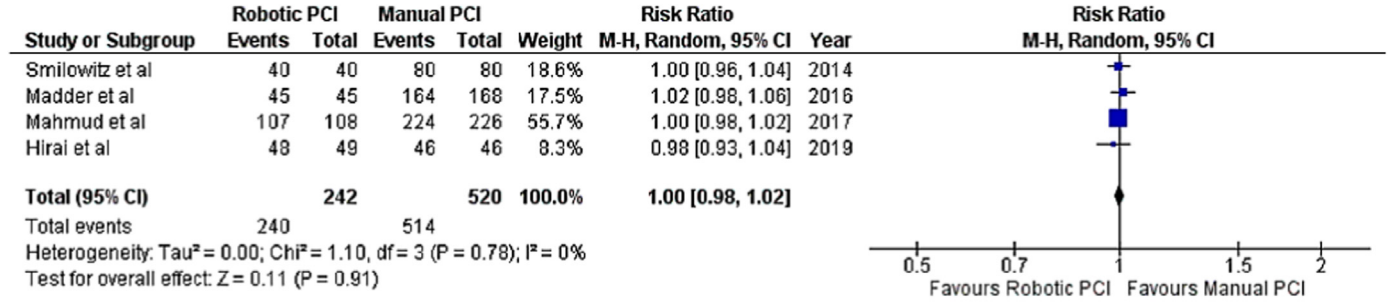

Figure 3B: Mean difference in procedure time

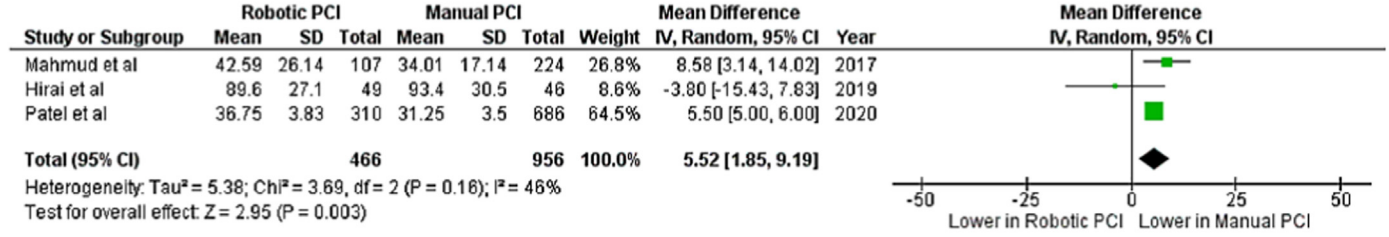

Figure 3C: Mean difference in contrast use

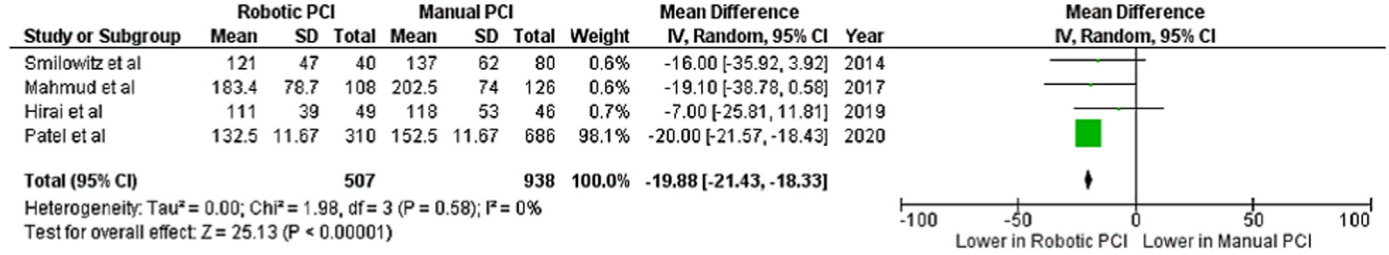

Figure 3D: Mean difference in fluoroscopy time

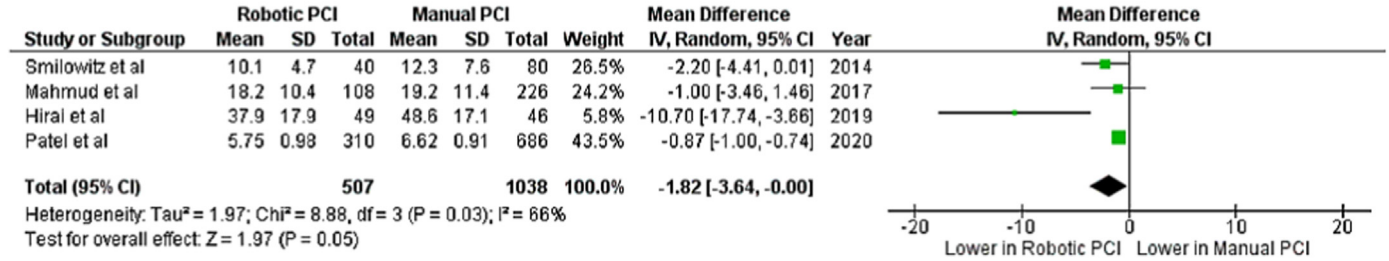

Figure 3E: Mean difference in radiation exposure

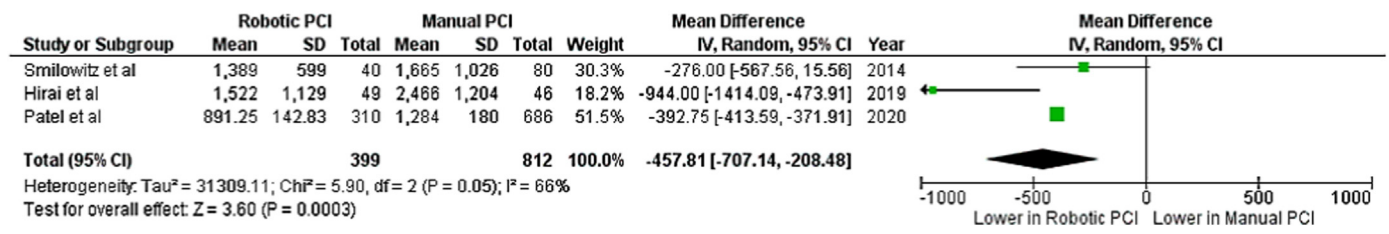

Fig. 3. A: Risk estimates of clinical success. B: Mean difference in procedure time. C: Mean difference in contrast use. D: Mean difference in fluoroscopy time. E: Mean difference in radiation exposure.

impact of clinical presentations, lesion complexity and concurrent pharmacotherapy could not be assessed.

5. Conclusion

In this updated meta-analysis comparing R–PCI withS-PCI, there were no difference in outcomes between the two groups in terms of procedural success. R–PCI took longer than S–PCI but radiation dose, contrast volume and fluoroscopy times were lower with R–PCI. In addition, the non-tangible benefits of R–PCI related to occupational relief to the interventional cardiologist by not having to wear lead aprons for as long and reduced radiation exposure cannot be quantified.

Key questions

- What is already known about this subject?

Robotic assisted PCI can be safe and effective approach for simpler coronary lesions.

- What does this study add?

This study shows that Robotic assisted PCI has superior safety profile with reduced contrast and radiation exposure with comparable efficacy compared to standard PCI even for selected complex coronary lesions.

- How might this impact on clinical practice?

This study calls for greater utilization of Robotic assisted PCI to reduced occupation related hazards to operators, radiation and contrasted related injury to patients and minimize patient-catheterization laboratory staff exposure in ongoing COVID-19 pandemic.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ihj.2021.08.006.

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