Successful introduction of robotic-assisted percutaneous coronary intervention system into Japanese clinical practice: a first-year survey at single center

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Abstract
In Japan, a robotic-assisted PCI (R-PCI) system, the CorPath GRX System (Corindus Inc.), has been approved for clinical use in 2018, which is the first introduction of R-PCI into Japan. In this study, the clinical performance of the R-PCI system in the initial year at Kurume University Hospital was evaluated comparing with conventional manual PCI (M-PCI). A total of 30 R-PCI and 77 M-PCI procedures performed between April 2019 and March 2020, were retrospectively included. The primary outcome was the rate of clinical success defined as < 30% residual stenosis without in-hospital major adverse cardiovascular events (MACE). The secondary outcomes were fluoroscopy time, dose area product (DAP), amount of radiation exposure to operators and assistants, procedural time, and contrast volume. Propensity-matching technique was used to match each R-PCI lesion to the nearest M-PCI lesion without replacement. After propensity score matching, 30 R-PCI procedures in 28 patients and 37 M-PCI procedures in 35 patients were analyzed. Clinical success rate with R-PCI was favorable and comparable to M-PCI (93.3 vs. 94.6%, \( p = 0.97 \)), without any in-hospital MACE. The operator radiation exposure was significantly lower in R-PCI (0 vs. 24.5 \( \mu \)SV, \( p < 0.0001 \)). Radiation exposure to the patients was tended to be reduced by R-PCI (DAP: 77.6 vs. 100.2 Gycm², \( p = 0.07 \)). There were no statistically significant differences in radiation exposure to the assistant, fluoroscopy time, procedural time and contrast volume between the two groups (radiation exposure to the assistant: 10.5 vs. 10.0 \( \mu \)SV, \( p = 0.64 \), fluoroscopy time: 27.5 vs. 30.1 min, \( p = 0.55 \), procedural time: 72.4 vs. 61.6 min, \( p = 0.23 \), and contrast volume: 93.2 vs. 102.0 ml, \( p = 0.36 \)). R-PCI in selected patients demonstrated favorable clinical outcomes with dramatical reduction of radiation exposure to operators.

Keywords Radiation exposure · Percutaneous coronary intervention · Robotic-assisted procedures

Abbreviations
CTO Chronic total occlusion
DAP Dose area product
ISR In-stent restenosis
LAD Left anterior descending artery

LCX Left circumflex artery
LMT Left main trunk
MACE Major adverse cardiac events
MI Myocardial infarction
M-PCI Manual percutaneous coronary intervention
PCI Percutaneous coronary intervention
QCA Quantitative coronary angiography
RCA Right coronary artery
R-PCI Robotic-assisted percutaneous coronary intervention
TVR Target vessel revascularization

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Introduction

Although several innovative devices related to percutaneous coronary intervention (PCI) have been developed, the fundamental operating style has not changed for long time. In conventional PCI, operators manipulate the devices under fluoroscopic guidance standing at the patients’ bedside, while wearing heavy lead aprons and other radiation protection devices. These unfriendly environment to the operators is well known to be associated with operators’ complications such as cancer, cataracts, orthopedic issues, and other medical problems [1–3].

A remote-controlled robotic-assisted system for PCI, the CorPath System (Corindus Inc., Waltham, MA, the United States) has been developed to address such limitations. Robotic-assisted PCI (R-PCI) enables operators to manipulate PCI devices remotely sitting down at a radiation-shielded cockpit. In addition, R-PCI provides precise lesion measurement and improved device positioning, which may lead to reduce radiation exposure to patients as well as radiation exposure to operators.

In 2018, the second-generation R-PCI system, the CorPath GRX system (Corindus Inc.) has been approved for clinical use in Japan, which is the first introduction of R-PCI into Japan. We reported our first case series in Japan [4]. In this study, we evaluated the clinical performance of the R-PCI system in the initial year after introduction to our hospital, comparing with manual PCI (M-PCI) in the same time frame.

Materials and methods

This was a retrospective, single-center, non-randomized study. Between April 2019 and March 2020, a total of 30 robotic-assisted PCI (R-PCI) procedures in 28 patients were performed by 3 trained operators at Kurume University Hospital (operator A: 21 procedures, operator B: 7 procedures and operator C: 2 procedures). The followings were the exclusion criteria to R-PCI in our center: patients with acute myocardial infarction (MI), chronic total occlusion (CTO) lesions, lesions expected to be required use of atherectomy device, and cardiogenic shock required mechanical support devises such as intra-aortic balloon pumping, extra-corporeal membrane oxygenation or temporary ventricular support pump catheter.

All patients were provided written informed consent prior to each PCI procedure. This study was approved by the Institutional Review Board of Kurume University (certification number: 20073) and followed the Declaration of Helsinki and the ethical standards of the responsible committee on human experimentation. Because this was a retrospective study, written informed consent form each enrolled patient was waived, instead of that, we provided an opportunity to opt out.

Study outcomes and definitions

The primary outcome was clinical success rate. Clinical success was defined as less than 30% residual stenosis determined by a quantitative coronary angiography (QCA), without major adverse cardiovascular events (MACE) either within 72 h of the procedure or before hospital discharge, whichever occurred first. MACE was defined as a composite of cardiac death, MI and clinically driven target vessel revascularization by percutaneous or surgical methods. MI was defined as (1) elevated creatine kinase myocardial band isoenzyme (CK-MB) > 10 times the upper limit of normal (ULN) or cardiac troponin (cTn) values > 70 times ULN, or (2) CK-MB > 5 times ULN or cTn values > 35 times ULN with development of new pathological Q waves in two contiguous leads or left bundle branch block [5]. The secondary outcomes were procedural time, contrast volume, fluoroscopy time, dose area product (DAP), and amount of radiation exposure for main operator and assistant. Procedural time was defined as time during the engagement of guiding catheter into the coronary artery and the removal of the guiding catheter. To measure radiation exposure, the operator and the assistant wore an electronic pocket dosimeter (MYDOSE mini™, ALOKA CO., LTD., Tokyo) on their left-side neck. Robotic technical success defined as clinical success and the completion of the PCI procedure entirely robotically or with partial manual assistance were also assessed. Manual assistance was defined as temporary disengagement of the robotic drive to use bedside manipulation of either the guide catheter, guidewire, or delivery system, with ultimate completion of the procedure using the re-engaged robotic drive. Manual conversion was defined as the disengagement of the robotic drive to use bedside manipulation of either the guide catheter, guidewire, or delivery system, which was required until the end of the procedure. Since intravascular imaging modality such as intravascular ultrasound or optical coherence tomography is incompatible with the current CorPath system, imaging devices need to be manipulated manually. In this study, the use of intravascular imaging modality is defined as “planned manual assistance” and is excluded from manual assistance.

Robotic-assisted PCI system

The details of the CorPath GRX system were described elsewhere [6–8]. Briefly, the CorPath GRX system consists of an interventional cockpit and a bedside unit (Fig. 1). The interventional cockpit is a radiation-shielded mobile workstation

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that contains a console with joysticks and touchscreen controls to control movement of the balloon/stent delivery system, guidewire, or guiding catheter. The bedside unit consists of a single-use cassette, articulating arm, and robotic drive. During the PCI procedure, the single-use cassette is mounted on a robotic drive and loaded with interventional equipment, which translates commands from the cockpit to independently manipulate each device. The system allows the operator to remotely control the movement of PCI devices by increments as small as 1 mm proximally or distally. In addition, the system allows the operator to measure lesion lengths during guidewire or balloon catheter movement. The system meets all commercial 0.014-inch guidewires and rapid-exchange balloon/stent catheters, and standard coronary guiding catheters of various sizes. Gaining a vascular access, advancement, and engagement of the guiding catheter were performed manually. The fluoroscopy is controlled by the seated operator, and contrast injection and exchange of devices in the cassette are performed by the tableside assistant.

**Statistical analysis**

Continuous variables are presented as the means with standard deviations or the median and interquartile range, according to their normal or not normal distribution. Differences in continuous parameters were evaluated using an unpaired t-test or Mann–Whitney U test. Categorical variables are presented as frequency counts and intergroup comparisons were made using Fisher’s exact test or Chi-square test. To match lesion background between R-PCI and M-PCI, propensity score-matched analysis was performed. Binary logistic regression was performed to calculate the propensity score. Target vessel, the American College of Cardiology/American Heart Association (ACC/AHA) lesion classification, the presence of in-stent restenosis (ISR), small vessel lesion (less than 2.5 mm), moderate to severe calcified lesion, tortuosity (more than moderate), diffuse lesion (over 20 mm), and bifurcation lesion were included in the binary logistic regression to estimate the probability. A nearest-neighbor greedy caliper match technique using caliper size one-quarter of the SD (caliper = 0.05) was used to match each R-PCI patient to the nearest M-PCI patient without replacement. In the propensity score-matched cohort, comparisons were performed using unpaired t-test for numeric variables and Fisher’s exact test or Chi-square test for categorical variables. All statistical analyses were performed using SPSS Statistics software (version 23.0, SPSS Inc., Chicago, IL, the United States). A p value < 0.05 was considered statistically significant.
Results

Between April 2019 and March 2020, there were 217 PCI procedures at Kurume University Hospital. Of these, a total of 30 R-PCI procedures were performed (13.8%). From 187 M-PCI, we excluded 80 emergent PCI procedures and 30 procedures because of CTO-PCI or use of atherectomy devices. Finally, we included 30 R-PCI procedures in 28 patients with 48 lesions and 77 M-PCI procedures in 73 patients with 108 lesions in this analysis (Fig. 2).

Table 1 demonstrates patients’ background. There were no significant differences in clinical background between the R-PCI and the M-PCI. Regarding lesion characteristics, except the prevalence of bifurcation lesion, there were no significant differences in target vessel and prevalence of featured lesion such as calcified lesion, small vessel disease, diffuse lesion between the two groups (bifurcation lesion; R-PCI: 20.5% vs. M-PCI: 43.1%, \( p = 0.047 \)). In the both groups, more than 70% of lesions were treated with stent deployment and intracoronary imaging device was used in over 98% of lesions (Table 2).

Table 3 shows the study outcomes. Clinical success rate was 93.3% in the R-PCI and 92.2% in the M-PCI, respectively \( (p = 0.97) \). In the R-PCI, 2 procedures (6.7%) required partial manual assistance due to difficulty of guidewire crossing \( (n = 1) \) and stent delivery \( (n = 1) \), and 3 procedures (10.0%) were converted to manual procedure due to difficulty of guidewire crossing \( (n = 2) \) and balloon catheter delivery \( (n = 1) \). Two of the three R-PCI procedures required manual conversion resulted in failure even after manual conversion. These cases are summarized in Fig. 3.

In-hospital MACE did not occur in the two groups. There were no statistical differences in procedure time, fluoroscopy time and contrast volume between the two groups. Dose area product (DAP) and radiation exposure to the operators were significantly lower in the R-PCI (DAP: 77.6 vs. 104.8 Gycm², \( p = 0.02 \), operator radiation exposure: 0 vs. 0).

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**Table 1** Comparison of patient characteristics between the R-PCI and the M-PCI

|                  | R-PCI \( (n = 28) \) | M-PCI \( (n = 73) \) | \( p \) value |
|------------------|----------------------|----------------------|--------------|
| Age, years       | 70.9 ± 9.9           | 73.0 ± 11.3          | 0.39         |
| Male sex         | 75.0% (21)           | 60.3% (44)           | 0.25         |
| Prior PCI        | 57.1% (16)           | 43.8% (32)           | 0.25         |
| Prior MI         | 28.6% (8)            | 16.4% (12)           | 0.28         |
| Prior CABG       | 10.7% (3)            | 9.6% (7)             | 1.0          |
| Heart failure    | 35.7% (10)           | 27.4% (20)           | 0.56         |
| Diabetes mellitus| 60.7% (17)           | 53.4% (39)           | 0.66         |
| Hyperlipidemia   | 67.9% (19)           | 76.7% (56)           | 0.51         |
| Hypertension     | 75.0% (21)           | 86.3% (63)           | 0.29         |
| Prior stroke     | 14.3% (4)            | 15.1% (11)           | 1.0          |
| PAD              | 10.7% (3)            | 13.7% (10)           | 0.95         |
| Current smoker   | 53.6% (15)           | 42.5% (31)           | 0.44         |
| CKD              | 28.6% (8)            | 35.6% (26)           | 0.66         |
| Hemodialysis     | 14.3% (4)            | 8.2% (6)             | 0.59         |

All values are % (N) or mean ± standard deviation.

**Fig. 2** Patients enrollment flow.

CTO chronic total occlusion, PCI percutaneous coronary intervention.
21.5 μSV, *p* < 0.0001, respectively), while radiation exposure to the assistants did not differ between the two groups (10.5 vs. 9.0 μSV, *p* = 0.14).

**Propensity score-matched cohort**

After propensity score matching, 30 R-PCI procedures in 28 patients with 48 lesions and 37 M-PCI procedures in 35 patients with 45 lesions were analyzed. There were no significant differences in patients', lesion, and procedural characteristics between the two groups (Tables 4, 5). Regarding study outcomes, operator radiation exposure remained significantly lower in the R-PCI (0 vs. 24.5 μSV, *p* < 0.0001), and DAP tended to be lower in the R-PCI (77.6 vs. 100.2 Gycm², *p* = 0.07). There were no significant differences in radiation exposure to the assistants, fluoroscopy time, procedural time and contrast volume between the two groups (radiation exposure to assistants: 10.5 vs. 10.0 μSV, *p* = 0.64, fluoroscopy time: 27.5 vs. 30.1 min, *p* = 0.55, procedural time: 72.4 vs. 61.6 min, *p* = 0.23, and contrast volume: 93.2 vs. 102.0 ml, *p* = 0.36) (Table 6).

**Discussion**

The main findings of this paper are following; (1) clinical success rate with R-PCI achieved 93.3%; (2) sixteen percent of the R-PCI procedures required partial manual assistance or manual conversion; (3) R-PCI dramatically reduced radiation exposure to operators.

This is a first report that demonstrated favorable clinical results with R-PCI in Japan. In this study, half of the target
lesions were type B2/C lesions in R-PCI. Although two R-PCI procedures resulted in failure, overall clinical success rate with R-PCI achieved 93.3% without any in-hospital MACE. In the present study, 16.7% of the R-PCI procedures required partial manual assistance (6.7%) due to difficulty of guidewire crossing and stent delivery, and manual conversion (10.0%) due to difficulty of guidewire crossing and balloon catheter delivery. In the CORA-PCI study, the rates of partial manual assistance and manual conversion were 11.1% and 7.7%, respectively [8]. Similarly, Harrison et al. reported that 18.5% of their R-PCI procedures required either planned partial manual assistance (3.7%), unplanned...
Table 4  Patient characteristics in the propensity-matched cohort

|                  | R-PCI (n = 28) | M-PCI (n = 35) | p value |
|------------------|----------------|----------------|---------|
| Age, years       | 70.9 ± 9.9     | 73.9 ± 11.3    | 0.28    |
| Male sex         | 75.0% (21)     | 62.9% (22)     | 0.30    |
| Prior PCI        | 57.1% (16)     | 37.1% (13)     | 0.11    |
| Prior MI         | 28.6% (8)      | 20.0% (7)      | 0.43    |
| Prior CAGB       | 10.7% (3)      | 2.9% (1)       | 0.20    |
| Heart failure    | 35.7% (10)     | 28.6% (10)     | 0.55    |
| Diabetes mellitus| 60.7% (17)     | 51.4% (18)     | 0.46    |
| Hyperlipidemia   | 67.9% (19)     | 77.1% (27)     | 0.41    |
| Hypertension     | 75.0% (21)     | 88.6% (31)     | 0.16    |
| Prior stroke     | 14.3% (4)      | 20.0% (7)      | 0.55    |
| PAD              | 10.7% (3)      | 14.3% (5)      | 0.67    |
| Current smoker   | 53.6% (15)     | 45.7% (16)     | 0.54    |
| CKD              | 28.6% (8)      | 40.0% (14)     | 0.34    |
| Hemodialysis     | 14.3% (4)      | 8.6% (3)       | 0.47    |

All values are % (N) or mean ± standard deviation

R-PCI robotic-assisted percutaneous coronary intervention, M-PCI manual percutaneous coronary intervention,
PAD peripheral artery disease, PCI percutaneous coronary intervention, R-PCI robotic-assisted percutaneous coronary intervention

partial manual assistance (7.4%), or manual conversion (7.4%) due to limited guide catheter/ wire support issue or robotic platform limitations [9], which were comparable to our results. In conventional PCI, most of this kind lesions are treated under support of over-the-wire-type microcatheter or guide extension catheter which are incompatible with the current CorPath GRX system. Thus, the development of the new system which allows to manipulate microcatheters and guide extension catheters is strongly warranted for reduction of manual assistant and conversion.

Several papers have proven the reduction of radiation exposure to operator with R-PCI [6–10]. Likewise, the present study demonstrated a dramatical decrease in operator radiation exposure with R-PCI compared to M-PCI. This is an unimpeachable benefit of R-PCI. However, there have been no information on radiation exposure to assistant in R-PCI procedures. We had been concerned about an increasing assistant radiation exposure due to the absence of operator, like a “shield”. In this study, the radiation exposure to assistant with R-PCI was comparable to that with M-PCI. Regarding this point, we should make further effort to reduce assistant radiation exposure more by keeping a certain distance from the X-ray generator during procedure.

A recent large-scale retrospective single-center study demonstrated the significant reduction of patients’ radiation exposure with R-PCI compared to M-PCI [10]. R-PCI can provide a precise device positioning and decreased operator strain and fatigue during the procedure, which may minimize fluoroscopy times. In contrast, this study showed that there was a trend to reduce radiation exposure to patients by R-PCI, but not statistically significant. This would be attributed to our team’s lack of experience and small sample size. Since R-PCI system is a novel and new technology, experience of both operator and assistant is very important. A previous study reported that R-PCI operators could reduce procedure and fluoroscopy time after three cases [11]. Thus, more experience of the operators and assistants may be able to further improve radiation exposure to both patients and assistants. To confirm the true benefit to patients, large-scale randomized R-PCI vs. M-PCI trials should be warranted. In this study, the procedural time was about 10 min longer in R-PCI than that in manual PCI, which was consistent with the previous studies [8, 10]. This could be caused by more time in robotic drive setup and loading the robotic drive with PCI devices. The CORA-PCI demonstrated that the low complexity procedure had significantly longer procedure time with R-PCI; whereas, this would be diluted by a lengthier overall procedure time in the intermediate- and high-complexity procedures.

Recently, another potential benefit of R-PCI has been raising. In R-PCI with the present CorPath system, someone needs to be close to the table for preparation of the patient and exchange the PCI devices in the cassette. However, except those timings, all staff can stay away from the table-side; consequently, R-PCI could minimize the proximity to the patient for the majority of the procedure. Therefore, in a pandemic such COVID-19 [12, 13], R-PCI may be useful to reduce the exposure risk to healthcare providers in the management of patients at high risk for COVID-19 or confirmed positives that require coronary intervention [14, 15].

Limitations

First, this was a retrospective study. Even though propensity score matching was adopted to minimize differences between the two groups, a potential bias and residual confounding could not be eliminated. Second, this was a small-size and single-center study. Third, target lesions included in this study were relatively simple. To evaluate the safety and efficacy of the CorPath GRX system in the Japanese real-world practice, the nationwide post-marketing surveillance is ongoing. The results are awaited.

Conclusions

R-PCI in selected patients demonstrated favorable clinical outcomes with dramatical reduction of radiation exposure to operators in Japanese clinical practice.
Table 5  Lesion and procedural characteristics in the propensity-matched cohort

|                          | R-PCI ($L = 48$) | M-PCI ($L = 45$) | $p$ value |
|--------------------------|------------------|------------------|-----------|
| **Vessel**               |                  |                  |           |
| LMT                      | 2.1% (1)         | 4.4% (2)         | 0.79      |
| LAD                      | 41.8% (20)       | 42.2% (19)       |           |
| LCX                      | 27.1% (13)       | 22.2% (10)       |           |
| RCA                      | 27.1% (13)       | 31.1% (14)       |           |
| Vein graft               | 2.1% (1)         |                  |           |
| **ACC/AHA classification (B2/C)** | 50.0% (23) | 53.3% (24) | 0.60 |
| ISR lesion               | 14.6% (7)        | 17.8% (8)        | 0.78      |
| Small vessel lesion ($\leq 2.5$ mm) | 39.6% (19) | 31.1% (14) | 0.52 |
| Moderate/severe calcified lesion | 20.8% (10) | 17.8% (8) | 0.80 |
| Tortuosity (< moderate)  | 27.1% (13)       | 42.4% (19)       | 0.19      |
| Diffuse lesion ($> 20$ mm) | 22.9% (11) | 24.4% (11) | 1.0 |
| Bifurcation lesion       | 25.0% (12)       | 33.3% (15)       | 0.49      |
| **QCA analysis**         |                  |                  |           |
| Lesion length (mm)       | 15.2 ± 7.8       | 15.5 ± 9.6       | 0.86      |
| Reference diameter (mm)  | 2.64 ± 0.62      | 2.64 ± 0.60      | 1.0       |
| Minimum lumen diameter (mm) | 0.66 ± 0.38 | 0.66 ± 0.44 | 0.95 |
| Pre % stenosis           | 75.4 ± 11.7      | 73.3 ± 18.7      | 0.51      |
| Post % stenosis          | 14.6 ± 13.2      | 14.3 ± 9.1       | 0.90      |
| **Procedural background**|                  |                  |           |
| Access site              |                  |                  | 0.59      |
| Radial                   | 60.4% (29)       | 71.1% (32)       |           |
| Brachial                 | 0                | 2.2% (1)         |           |
| Femoral                  | 39.6% (19)       | 26.7% (12)       |           |
| Stenting                 | 72.9% (35)       | 84.4% (38)       | 0.18      |
| Pre-dilatation           | 91.7% (44)       | 84.4% (38)       | 0.28      |
| Post-dilatation          | 29.2% (14)       | 46.7% (21)       | 0.08      |
| Intravascular imaging modality | 97.9% (47) | 100% (45) | 0.33 |

All values are % ($N$) or mean ± standard deviation

ACC American College of Cardiology, AHA American Heart Association, ISR in-stent restenosis, LAD left anterior descending artery, LCX left circumflex artery, LMT left main trunk, M-PCI manual percutaneous coronary intervention, QCA quantitative coronary angiography, RCA right coronary artery, R-PCI robotic-assisted percutaneous coronary intervention
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Compliance with ethical standards

Conflict of interest

All authors have no conflict of interest to disclose.

References

1. Roguin A, Goldstein J, Bar O (2012) Brain tumours among interventional cardiologists: a cause for alarm? Report of four new cases from two cities and a review of literature. Eurointervention 7:1081–1086
2. Vano E, Kleiman NJ, Duran A, Rehani MM, Echeverri D, Cabrera M (2010) Radiation cataract risk in interventional cardiology personnel. Radiat Res 174:490–495
3. Goldstein JA, Balter S, Cowley M, Hodgson J, Klein LW, Interventional Committee of the Society of Cardiovascular Interventions (2004) Occupational hazards of interventional cardiologists: prevalence of orthopedic health problems in contemporary practice. Catheter Cardiovasc Inter 63:407–419
4. Kagiyama K, Ueno T, Mitsutake Y, Yamaji K, Ishimatsu T, Sasaki K, Fukumoto Y (2019) First experience of robotic-assisted percutaneous coronary intervention in Japan. Intern Med 58:3415–3419
5. Moussa ID, Klein LW, Shah B, Mehran R, Mack MJ, Brilakis ES, Reilly JP, Zoghbi G, Holper E, Stone GW, Society for Cardiovascular Angiography and Interventions (2014) Consideration of a new definition of clinically relevant myocardial infarction after coronary revascularization: an expert consensus document from the Society for Cardiovascular Angiography and Interventions (SCAI). Catheter Cardiovasc Inter 83:27–36
6. Weisz G, Metzger DC, Caputo RP, Delgado JA, Marshall JJ, Vetrovec GW, Reisman M, Waksman R, Granada JF, Novack V, Moses JW, Carrozza JP (2013) Safety and feasibility of robotic percutaneous coronary intervention: PRECISE (percutaneous robotically-enhanced coronary intervention) study. J Am Coll Cardiol 61:1596–1600
7. Smitsom CC, Ang L, Pourdjabbar A, Reeves R, Patel M, Mahmud E (2018) Safety and feasibility of a novel, second-generation robotic-assisted system for percutaneous coronary intervention: first-in-human report. J Invasive Cardiol 30:152–156
8. Mahmud E, Naghi J, Ang L, Harrison J, Behnamfar O, Pourdjabbar A, Reeves R, Patel M, Patel MP, Reeves RR, Mahmud E (2018) Robotic-assisted percutaneous coronary intervention: reasons for partial manual assistance or manual conversion. Cardiovasc Revasc Med 19:526–531
9. Patel TM, Shah SC, Soni YY, Radadiya RC, Patel GA, Tiwari PO, Pancholy SB (2020) Comparison of robotic percutaneous coronary intervention with traditional percutaneous coronary intervention: a propensity score-matched analysis of a large cohort. Circ Cardiovasc Inter 13:e008888. https://doi.org/10.1161/CIRCINTERVENTIONS.119.008888
10. Weisz G, Smilowitz NR, Metzger DC, Caputo R, Delgado J, Marshall JJ, Vetrovec G, Reisman M, Waksman R, Pichard A, Granada JF, Moses JW, Carrozza JP (2014) The association between experience and proficiency with robotic-enhanced coronary
intervention—insights from the PRECISE multi-center study. Acute Card Care 16:37–40
12. World Health Organization. Naming the coronavirus disease (COVID-19) and the virus that causes it. Available at https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/naming-the-coronavirus-disease-(covid-2019)-and-the-virus-that-causes-it Accessed 20 Sept 2020
13. Moschini L, Loffi M, Regazzoni V, Di Tano G, Gherbesi E, Danzi GB (2020) Effects on QT interval of hydroxychloroquine associated with ritonavir/darunavir or azithromycin in patients with SARS-CoV-2 infection. Heart Vessels. https://doi.org/10.1007/s00380-020-01671-4
14. Tabaza L, Virk HUH, Janzer S, George JC (2020) Robotic-assisted percutaneous coronary intervention in a COVID-19 patient. Catheter Cardiovasc Interv. https://doi.org/10.1002/ccd.28982
15. Vlachakis PK, Tentolouris A, Kanakakis I (2020) Concerns for management of STEMI patients in the COVID-19 era: a paradox phenomenon. J Thromb Thrombolysis. https://doi.org/10.1007/s11239-020-02236-y

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