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# A comparative study of robotic-assisted and conventional-manual percutaneous coronary intervention using intravascular ultrasound guidance

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Abstract

Prior investigations have suggested that angiographic-guidance robotic-assisted PCI (R-PCI) is linked to lower radiation exposure, and contrast dose, compared with conventional-manual PCI (C-PCI). We aimed to evaluate the safety of Intravascular Ultrasound (IVUS)-guided R-PCI compared with IVUS-guided C-PCI. A total of 807 PCI procedures (692 C-PCI, 115 R-PCI) were performed in our hospital between 2019 and 2021. To adjust for baseline and lesion features between the two groups, a propensity score matching analysis was conducted (91 vs. 91). The primary endpoints were contrast agent utilization, skin dose exposure, and total fluoroscopy time.

Secondary endpoints were outcomes at 30 days and 1 year. The median contrast dose (70.6 mL vs. 88.4 mL, $p < 0.001$), patient skin dose (0.7 Gy vs. 1.0 Gy, $p = 0.013$), and fluoroscopy time (19.5 min vs. 25.9 min, $p < 0.001$) were all significantly lower in the R-PCI group. There were no cardiovascular events at 30 days in the R-PCI or C-PCI group, and cardiovascular death tended to be higher at 1 year in the C-PCI group (0% vs. 3.3%, $p = 0.082$). Patient exposure to contrast and radiation was significantly lower with better cardiovascular outcomes in the robotic-assisted PCI group in an IVUS-guided setting.

*Key words*: *robotic-assisted percutaneous coronary intervention, intravascular ultrasound, longitudinal geographic miss*

## I. Introduction

In recent years, percutaneous coronary intervention (PCI) has revolutionized the management of coronary artery disease (CAD), offering a minimally invasive alternative to traditional open-heart surgeries[1,2]. The continual advancements in interventional cardiology have led to the introduction of robotic-assisted PCI (R-PCI), utilizing systems such as the CorPath GRX System (Siemens Healthineers, Forchheim, Germany), which aim to enhance the precision and safety of coronary interventions[3,4]. R-PCI involves the use of a robotic platform to perform the procedure under the guidance and

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control of an interventional cardiologist. This innovative technology offers potential advantages, including enhanced procedural accuracy, improved dexterity, reduced radiation exposure, and the ability to perform interventions remotely[4-6]. These features have garnered significant interest and prompted extensive research to explore the clinical utility and efficacy of robotic-assisted PCI. Longitudinal geographic miss (LGM) is the failure to fully cover a diseased coronary segment during PCI procedures, and one of the benefits on the patient side is that the use of robotic systems has been reported to reduce LGM using angiography guidance[7,8].

One of the crucial components of PCI is intravascular ultrasound (IVUS), which provides real-time imaging of the coronary arteries, facilitating accurate lesion assessment and guiding stent placement [9,10]. IVUS has become a valuable tool for interventional cardiologists because it enables the identification of complex lesions, evaluation of plaque morphology, and optimization of stent deployment [11-14]. However, there have been no reports comparing robotic versus conventional PCI in IVUS-guidance. In addition, Siemens Healthineers has announced that it will stop selling the CorPath GRX System, a treatment support robot, for cardiac catheterization. In the present study, we aimed to evaluate the safety of IVUS-guided robotic PCI compared with IVUS-guided conventional PCI.

## II. Materials and Methods

This retrospective, single-center, observational study compared IVUS-guided R-PCI and C-PCI. A total of 807 PCI procedures (692 C-PCI, 115 R-PCI) were performed in our hospital between June 12, 2019, and June 11, 2021. The patient inclusion criteria were age ≧ 18 and stable ischemic coronary disease (effort angina or silent myocardial ischemia), which is the clinical indication for PCI with a drug-eluting stent. The exclusion criteria were as follows: (1) known severe coronary calcification treated with a debulking device, (2) acute coronary syndrome, (3) tortuous artery preventing IVUS catheter passage, (4) chronic total occlusion, (5) bypass graft stenosis, (6) in-stent restenosis treated with a drug-coated balloon without stent deployment, (7) transcatheter aortic valve replacement, (8) mechanical circulatory support, (9) optical coherence tomography guidance, and (10) without stenting or final intravascular imaging. A total of 372 cases of PCI (R-PCI: 105, C-PCI: 267) meeting these criteria were analyzed. To eliminate selection bias between the two groups, propensity score matching was conducted. Prior to calculating the propensity scores, to avoid counting the same patient multiple times, data from subsequent PCIs after the first one during the study period were excluded for patients who underwent multiple PCIs.

The primary endpoints of this study were contrast agent utilization, skin dose exposure, and total fluoroscopy time. Secondary endpoints were outcomes at 30 days and 1 year (including all-cause death, cardiac death, and target vessel revascularization) and incidence of LGM.

This study was approved by the Institutional Review Board of our hospital, and eligible patients provided written informed consent before participation (MH2020-132).

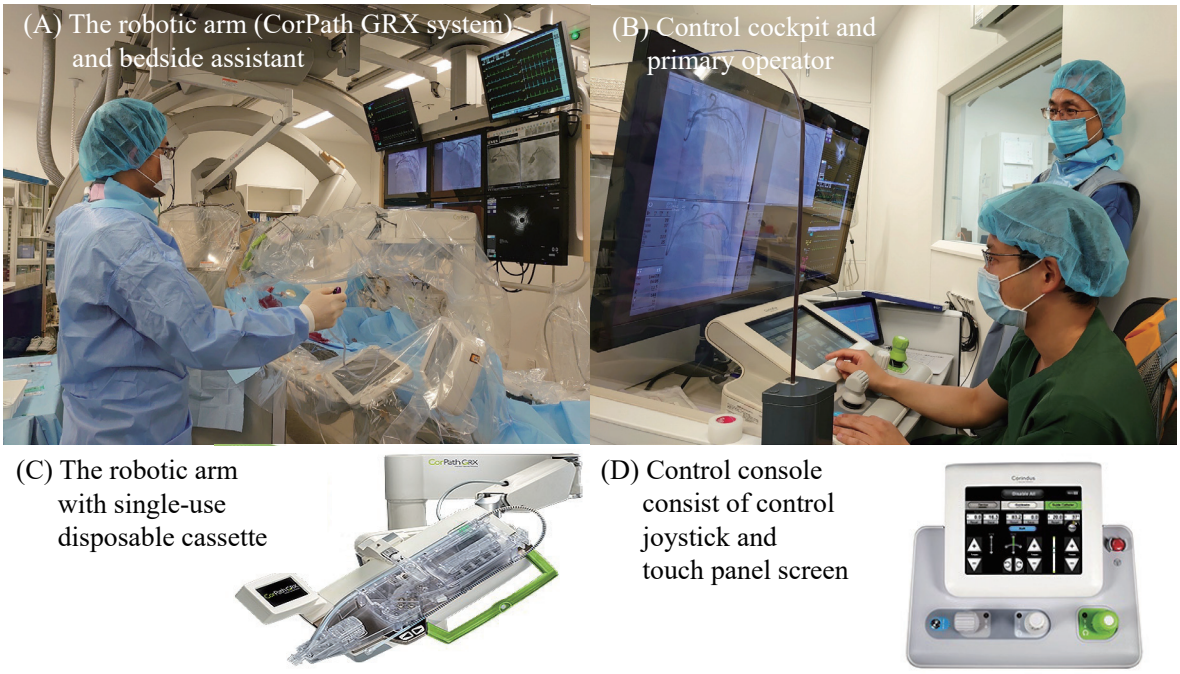


Fig. 1. The CorPath GRX robotic interventional system
(A) The robotic arm and bedside assistant. (B) Control cockpit and primary operator.
(C) The robotic arm with single-use disposable cassette.
(D) Control console consisting of control joystick and touch panel screen.

1. Robotic Percutaneous Coronary Intervention

Robotic-assisted PCI was conducted using the second-generation CorPath GRX System developed by Siemens Healthineers, Forchheim, Germany. The CorPath GRX system comprises an interventional cockpit - a radiation-shielded, mobile workstation - and a bedside unit (Fig. 1). The interventional cockpit is equipped with a touchscreen panel and joystick, enabling control over the guiding catheter, interventional wire, and balloon/stent (Fig. 1D). The bedside unit, positioned as an extendable and retractable arm on the catheter bed, houses a disposable cassette for each treatment session (Fig. 1. C). The procedural steps involve the second operator puncturing the artery, inserting the therapeutic sheath, and guiding the catheter into the coronary artery. Subsequently, the preparatory stage entails loading the disposable cassette into the robotic arm and attaching wires and devices to the cassette (Fig. 1A). The primary operator, seated at a distance from the patient in the cockpit, can introduce devices and adjust stent positioning using a joystick or touchscreen (Fig. 1B). Lesion length is measured through a balloon pull-back system, and device position can be finely adjusted in 1 mm increments using the touchscreen. Device replacement and troubleshooting tasks are undertaken by a second operator at the bedside. Notably, the IVUS catheter utilized in this study must be operated manually, as it is not compatible with the robotic system. In cases where wire control and device delivery become challenging during robotic PCI, the treatment approach may be switched to conventional manual PCI.

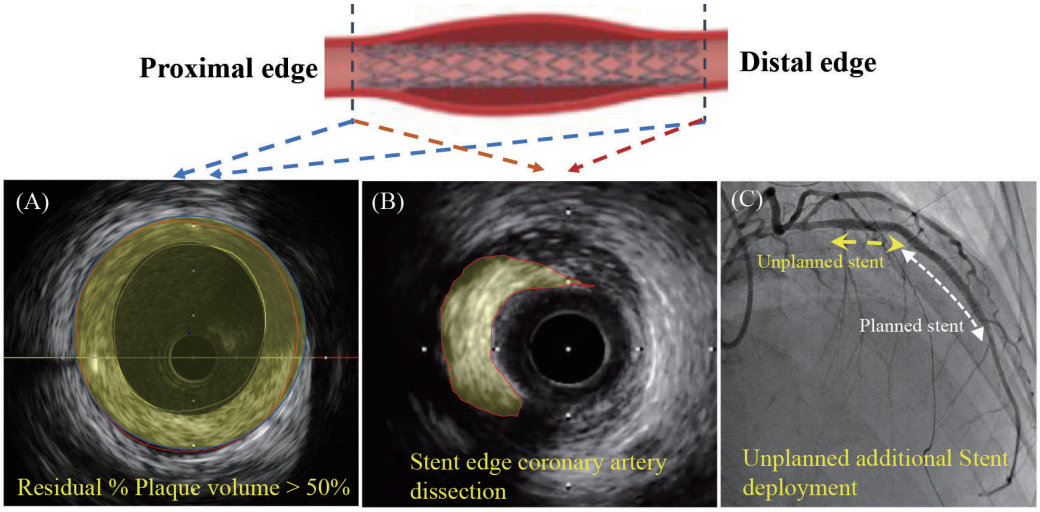


Fig. 2. Definition of longitudinal geographic miss
Longitudinal geographic miss (LGM) is defined as a residual % plaque volume > 50% (A), stent edge dissection (B), or unplanned additional stent deployment due to plaque shift or stent edge dissection (C).

2. IVUS and quantitative coronary angiography analysis

IVUS was performed according to Judkin's technique via the trans-radial approach using a 6-French system. The present study used the VISIWAVE™ imaging system with the AltaView™ imaging catheter (Terumo Corporation, Tokyo, Japan) or the I-Lab™ imaging system with the OptiCross™ imaging catheter (Boston Scientific, Boston Scientific Way, Marlborough, MA, USA). After inserting a 0.36-mm intervention guide wire, the imaging catheter was carefully advanced distally to the target lesion under fluoroscopic guidance.

In the C-PCI group, IVUS-guided marking of the stent landing position was demonstrated manually by the operator. In the R-PCI group, the robotic system had to be disconnected because imaging catheters (AltaView™ and OptiCross™) were not compatible with the robotic arm and the catheters had their own auto pullback systems. IVUS-guided landing positions were manually marked as in the C-PCI group. IVUS measurements were obtained using the conventional manual method and not integrated into the robotic PCI system. The stent length was based on the gold standard for manual IVUS measurements [15]. All post-PCI IVUS images were assessed for stent length, minimum stent area, and percent plaque volume (%PV) at the proximal and distal margins in the R-PCI vs. C-PCI groups.

LGM was defined as a residual %PV > 50% at the proximal and distal margins, stent edge dissection, or additional stent deployment immediately after stenting (Fig. 2) [8]. Stent edge dissections were defined as follows: (1) intimal dissection, (2) medial dissection, (3) intramural hematoma, and (4) extra-medial injury [16]. Intimal dissection was defined as a dissection with a tear limited to the intima.

IVUS analysis using Echo plaque 4.0 IVUS imaging software (INDEC systems, Santa Clara, CA, USA) was performed by two experienced observers (Takumi Kimura and Yorihiko Koeda) not involved with PCI.

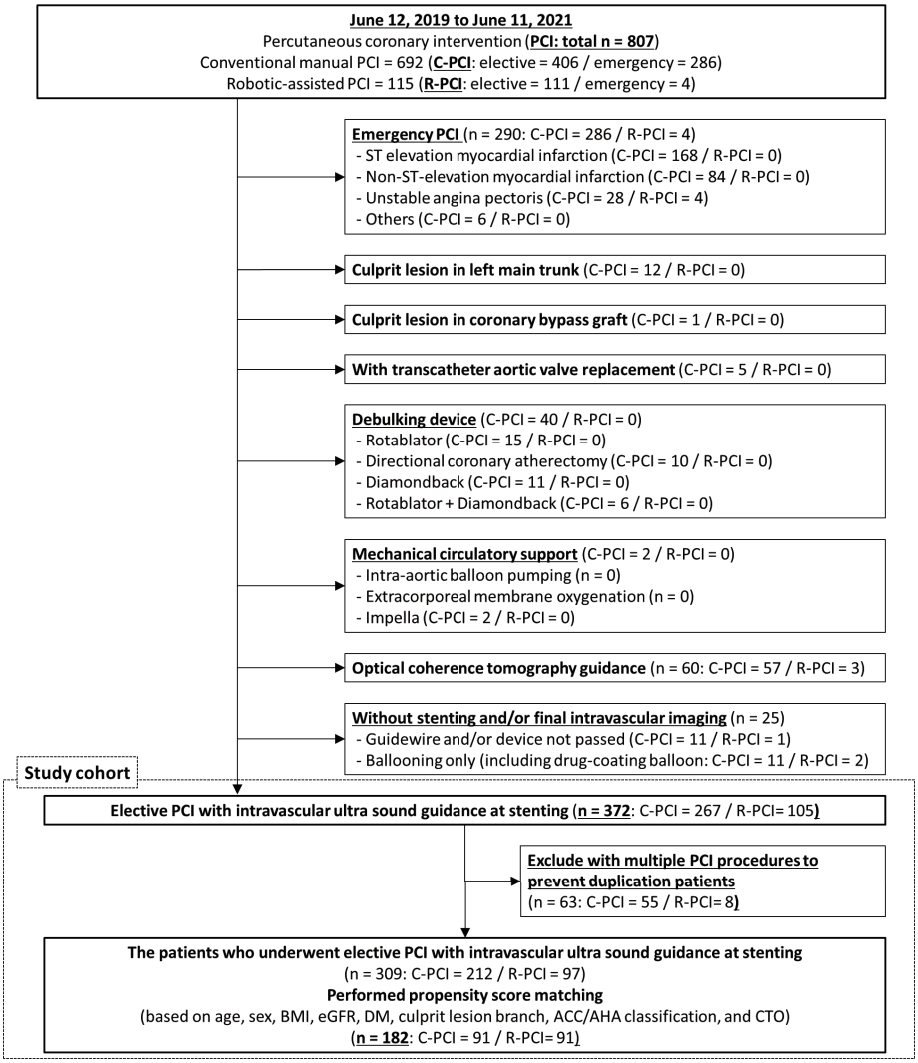


Fig. 3. Flowchart of inclusion and exclusion criteria
Exclusion criteria were "emergency case," "culprit lesion in the left main trunk," "culprit lesion in a coronary bypass graft," "with transcatheter aortic valve replacement," "treated with debulking device," "with mechanical circulatory support," "optical coherence tomography guidance," and "without stenting or final intracoronary imaging," . Propensity score matching of patients was performed based on age, sex, BMI, eGFR, DM, culprit lesion branch, ACC/AHA classification, and Chronic Total Occlusion.

Images were evaluated and interpreted through discussions between both experienced observers. The target lesion was defined using a stent landing segment with a 5-mm addition to both the proximal and distal sides.

All-cause death, cardiovascular death, and target lesion revascularization were assessed at the 30-day and 1-year follow-up after index PCI.

The target lesion was analyzed using QCA on a QCA-CMS system version 7.1 (Medis Medical Imaging Systems, Leiden, The Netherlands) using the isocenter technique, which enables automatic image calibration as the standard method [17]. Minimal lumen area, lesion length, percent diameter stenosis, and reference diameter were measured using QCA-CMS. Percent diameter stenosis was calculated from the minimal lumen diameter and reference diameter.

3. Statistical analysis

All statistical analyses were performed using SPSS Ver. 28 for Windows (Chicago, IL, USA). Continuous values were presented as mean ± standard deviation and interquartile range according to their normal or not normal distribution. Categorical variables are presented as counts and percentages. Differences in continuous parameters are

Table 1. Clinical characteristics

| | (A) Baseline data | | | (B) Data after propensity score matching | | |
|---|---|---|---|---|---|---|
| | Robotic PCI (n = 105) | Conventional PCI (n = 267) | p value | Robotic PCI (n = 91) | Conventional PCI (n = 91) | p value |
| Age (years) | 71.0 ± 9.5 | 70.5 ± 11.0 | 0.783 | 71.5 ± 9.6 | 71.6 ± 11.0 | 0.898 |
| Male (%) | 81 (77) | 210 (79) | 0.751 | 68 (75) | 67 (74) | 0.866 |
| BMI (kg/m$^2$) | 24.8 ± 3.7 | 24.8 ± 3.8 | 0.972 | 24.8 ± 3.6 | 24.4 ± 3.8 | 0.384 |
| Hypertension, n (%) | 95 (91) | 239 (91) | 0.782 | 83 (91) | 84 (92) | 0.788 |
| Diabetes, n (%) | 52 (50) | 148 (55) | 0.304 | 43 (47) | 40 (44) | 0.655 |
| Dyslipidemia, n (%) | 100 (95) | 250 (94) | 0.555 | 87 (96) | 84 (92) | 0.351 |
| Current smoker, n (%) | 14 (13) | 38 (14) | 0.822 | 13 (14) | 12 (13) | 0.830 |
| eGFR (mL/min/1.73 m$^2$) | 65.3 ± 16.4 | 55.2 ± 20.3 | < 0.001 | 64.2 ± 15.9 | 61.6 ± 17.1 | 0.360 |
| LDL-C (mg/dL) | 87.5 ± 33.9 | 92.4 ± 33.1 | 0.152 | 89.4 ± 33.9 | 94.9 ± 32.4 | 0.147 |
| HDL-C (mg/dL) | 48.4 ± 13.2 | 47.5 ± 11.8 | 0.779 | 48.2 ± 13.6 | 49.9 ± 11.9 | 0.192 |
| HbA1c (%) | 6.6 ± 1.2 | 6.6 ± 1.1 | 0.947 | 6.6 ± 1.2 | 6.4 ± 1.0 | 0.586 |

BMI, body mass index; LVEF, Left ventricle ejection fraction; eGFR, estimated glomerular filtration rate; LDL-C, low density lipoprotein-cholesterol; HDL-C, high-density lipoprotein-cholesterol.

evaluated using an unpaired t-test or Mann-Whitney U test between the R-PCI and C-PCI groups. This study employed a two-group comparison using the chi-square test to analyze the occurrence of cardiovascular mortality, and target lesion revascularization. Differences were considered significant at $p < 0.05$. The propensity scores were based on factors affecting the patient's coronary artery lesions and outcomes post-PCI (age, gender, BMI, eGFR, DM, culprit vessel, ACC_AHA classification, and presence of CTO). The standard deviation of the propensity scores was 0.162, and propensity score matching was performed using a tolerance of 0.04, which is 25% of this value (91 vs. 91). A flowchart of the analyzed subjects is presented in Figure 3.

## III. Results

The baseline data prior to propensity score matching are presented in Tables 1A, 2A, 3A, and 5A, respectively. In this section, the focus is primarily on the data following propensity score matching.

The robotic PCI group was compared with the propensity-matched conventional PCI group (91 robotic vs. 91 conventional PCIs). Table 1B shows the baseline clinical characteristics. There were no significant differences in risk factors and laboratory data (eGFR, hemoglobin, and lipid profiles) between the groups. The baseline lesion and interventional characteristics are detailed in Table 2B. The mean number of diseased vessels in the C-PCI group tended to be higher (1.6 vs. 1.4, $p = 0.084$), and the lesion length was longer (23.8mm vs. 20.3mm, $p = 0.102$) in the C-PCI group. Approximately 60% of lesions were of American College of Cardiology Foundation/American Heart Association classification type B2 or C in both groups. The median contrast dose (70.6 mL vs. 88.4 mL, $p < 0.001$, Figure 4, Table 2B), total radiation exposure dose (0.7 Gy vs. 1.0

Table 2. Lesion and interventional characteristics

| | (A) Baseline data | | | (B) Data after propensity score matching | | |
|---|---|---|---|---|---|---|
| | Robotic PCI (n = 105) | Conventional PCI (n = 267) | p value | Robotic PCI (n = 91) | Conventional PCI (n = 91) | p value |
| Mean number of diseased vessels | 1.4 ± 0.7 | 1.6 ± 0.7 | 0.050 | 1.4 ± 0.6 | 1.6 ± 0.7 | 0.084 |
| Mean number of stent use | 1.2 ± 0.4 | 1.5 ± 0.6 | 0.003 | 1.2 ± 0.4 | 1.2 ± 0.4 | 0.878 |
| Lesion length measured by angiography (mm) | 20.8 ± 10.3 | 24.1 ± 14.9 | 0.165 | 20.3 ± 9.7 | 23.8 ± 14.8 | 0.102 |
| Culprit location | | | | | | |
| Left main coronary artery, n (%) | 0 (0) | 0 (0) | 0.523 | 0 (0) | 0 (0) | 0.977 |
| Left anterior descending artery, n (%) | 52 (50) | 133 (50) | | 47 (51) | 47 (51) | |
| Left circumflex artery, n (%) | 27 (26) | 56 (21) | | 21 (23) | 20 (22) | |
| Right coronary artery, n (%) | 26 (25) | 78 (29) | | 23 (25) | 24 (26) | |
| ACC/AHA lesion classification B2/C, n (%) | 57 (62) | 208 (78) | < 0.001 | 57 (62) | 52 (57) | 0.196 |
| Total procedural time (min) | - | - | - | 56.1 ± 34.2 | 61.2 ± 40.3 | 0.357 |
| Total contrast media volume (ml) | 71.0 ± 22.1 | 96.0 ± 43.3 | < 0.001 | 70.6 ± 22.6 | 88.4 ± 43.7 | < 0.001 |
| Total fluoroscopy time (min) | 19.4 ± 15.1 | 31.2 ± 23.6 | < 0.001 | 19.5 ± 15.7 | 25.9 ± 17.1 | < 0.001 |
| Total radiation exposure dose (Gy) | 0.7 ± 0.5 | 1.5 ± 3.2 | < 0.001 | 0.7 ± 0.6 | 1.0 ± 0.7 | 0.013 |
| Radiation exposure to the operator (mSv) | 0 (0-1.2) | NA | NA | 0 (0-1.2) | NA | NA |
| Radiation exposure to the assistant (mSv) | 28 (12-58) | NA | NA | 28 (12-58) | NA | NA |

All values are N (%), mean ± standard deviation, or median (interquartile range).
PCI, percutaneous coronary intervention; ACC, American College of Cardiology; AHA, American Heart Association; NA, not available.

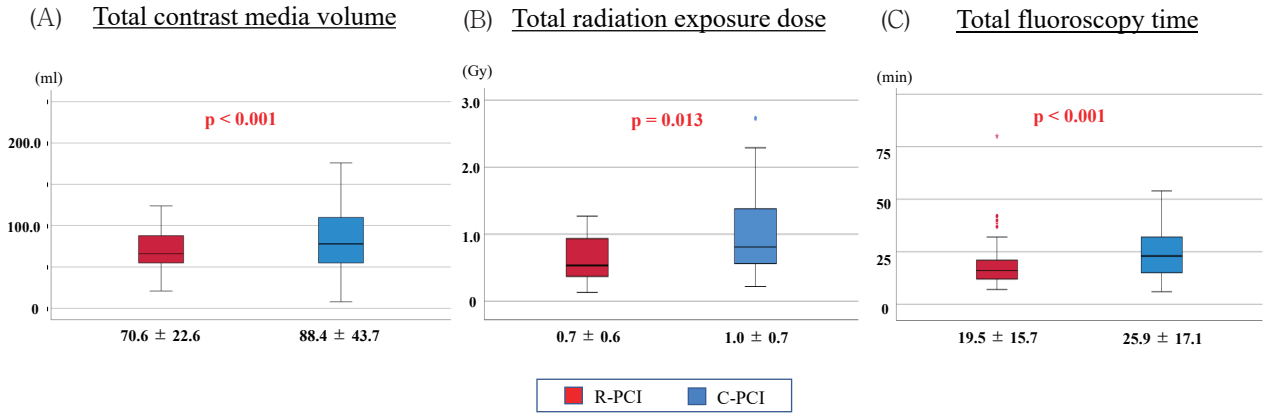


Fig. 4. Comparison of total contrast volume, total radiation exposure, and total fluoroscopy time between the R-PCI and C-PCI groups
(A) The median contrast dose (70.6 mL vs. 88.4 mL, $p < 0.001$)
(B) Total radiation exposure (0.7 mSv vs. 1.0 mSv, $p = 0.013$)
(C) Fluoroscopy times (19.5 min vs. 25.9 min, $p < 0.001$) were all significantly lower in the R-PCI group.

Table 3. Quantitative coronary angiography (QCA) parameters and Intravascular Ultrasound (IVUS) parameters after the stent placement

| | (A) Baseline data | | | (B) Data after propensity score matching | | |
|---|---|---|---|---|---|---|
| | Robotic PCI (n = 105) | Conventional PCI (n = 267) | p value | Robotic PCI (n = 91) | Conventional PCI (n = 91) | p value |
| QCA parameters pre stent placement | | | | | | |
| TIMI grade n 3/2/1/0 | 94/9/2/0 | 195/30/16/6 | < 0.001 | 83/7/1/0 | 81/7/1/2 | 0.567 |
| Lesion length (mm) | 20.8 ± 10.3 | 24.1 ± 14.9 | 0.165 | 20.3 ± 9.7 | 23.8 ± 14.8 | 0.102 |
| Reference diameter (mm) | 2.47 ± 0.66 | 2.31 ± 0.75 | 0.107 | 2.49 ± 0.70 | 2.38 ± 0.58 | 0.180 |
| Minimum lumen diameter (mm) | 0.63 ± 0.33 | 0.52 ± 0.42 | 0.006 | 0.63 ± 0.33 | 0.59 ± 0.39 | 0.593 |
| % diameter stenosis (%) | 74.5 ± 11.3 | 78.6 ± 14.5 | 0.019 | 74.4 ± 11.3 | 75.9 ± 13.6 | 0.502 |
| QCA parameters post stent placement | | | | | | |
| TIMI grade n 3/2/1/0 | 105/0/0/0 | 261/4/1/1 | 0.494 | 91/0/0/0 | 91/0/0/0 | 1.000 |
| Stent length (mm) | 27.3 ± 9.2 | 27.2 ± 9.0 | 0.986 | 24.8 ± 9.1 | 23.8 ± 14.8 | 0.421 |
| Reference diameter (mm) | 2.93 ± 0.48 | 3.09 ± 0.59 | 0.007 | 2.94 ± 0.49 | 3.01 ± 0.55 | 0.267 |
| Minimum lumen diameter (mm) | 2.58 ± 0.45 | 2.71 ± 0.56 | 0.009 | 2.59 ± 0.45 | 2.72 ± 0.51 | 0.372 |
| % diameter stenosis (%) | 7.8 ± 2.3 | 8.8 ± 8.0 | 0.693 | 7.8 ± 2.3 | 7.9 ± 2.9 | 0.086 |
| IVUS parameters after the stent placement | | | | | | |
| Stent length (mm) | 27.3 ± 9.1 | 27.2 ± 9.0 | 0.986 | 27.0 ± 8.9 | 25.3 ± 8.8 | 0.799 |
| Minimum stent area ($mm^2$) | 5.9 ± 2.0 | 6.3 ± 2.2 | 0.087 | 6.0 ± 2.1 | 6.0 ± 2.2 | 0.593 |
| % plaque volume at the proximal margin (%) | - | - | - | 41.2 ± 7.9 | 41.4 ± 8.6 | 0.597 |
| % plaque volume at the distal margin (%) | - | - | - | 36.4 ± 8.7 | 38.4 ± 10.1 | 0.129 |
| Lumen area at the proximal margin ($mm^2$) | - | - | - | 8.2 ± 2.5 | 9.4 ± 2.9 | 0.259 |
| Lumen area at the distal margin ($mm^2$) | - | - | - | 6.2 ± 2.8 | 6.5 ± 2.5 | 0.733 |
| Vessel area at the proximal margin ($mm^2$) | - | - | - | 14.1 ± 4.1 | 16.1 ± 4.6 | 0.372 |
| Vessel area at the distal margin ($mm^2$) | - | - | - | 9.9 ± 4.4 | 11.0 ± 4.9 | 0.091 |

The data of % plaque volume, lumen area, and vessel area are limited to patients' post-propensity score matching. QCA, quantitative coronary angiography; IVUS, intravascular ultrasound.

Gy, p = 0.013), and fluoroscopy time (19.5 min vs. 25.9 min, p < 0.001) were all significantly lower in the R-PCI group. QCA and IVUS parameters are summarized in Tables 3A and 3B, and there were no significant differences between the groups. IVUS parameters after stent placement are summarized in Table 3B. MSAs were 6.0$mm^2$ and the residual % plaque area at the proximal and distal margins were approximately 40% in both groups, with no significant differences. The incidence of LGM, which is defined as a residual % plaque volume > 50%, stent edge dissection, or additional stent deployment, is indicated in Table 4. This cohort revealed a slightly lower incidence of LGM following PCI in the R-PCI

Table 4. Incidence of longitudinal geographic miss (LGM)

| | Robotic PCI (n = 91) | Conventional PCI (n = 91) | p value |
|---|---|---|---|
| Residual percent plaque volume > 50% | 9 (proximal: 5, distal:4) | 10 (proximal: 7, distal: 4) | 0.808 |
| Stent edge dissection | 2 (proximal: 2, distal:0) | 7 (proximal: 4, distal: 3) | 0.087 |
| Additional stent deployment | 0 | 1 | 0.316 |
| Total LGM, n (%) | 11 (12.1%) | 18 (19.7%) | 0.156 |

This data is limited to patients' post-propensity score matching. IVUS, intravascular ultrasound.

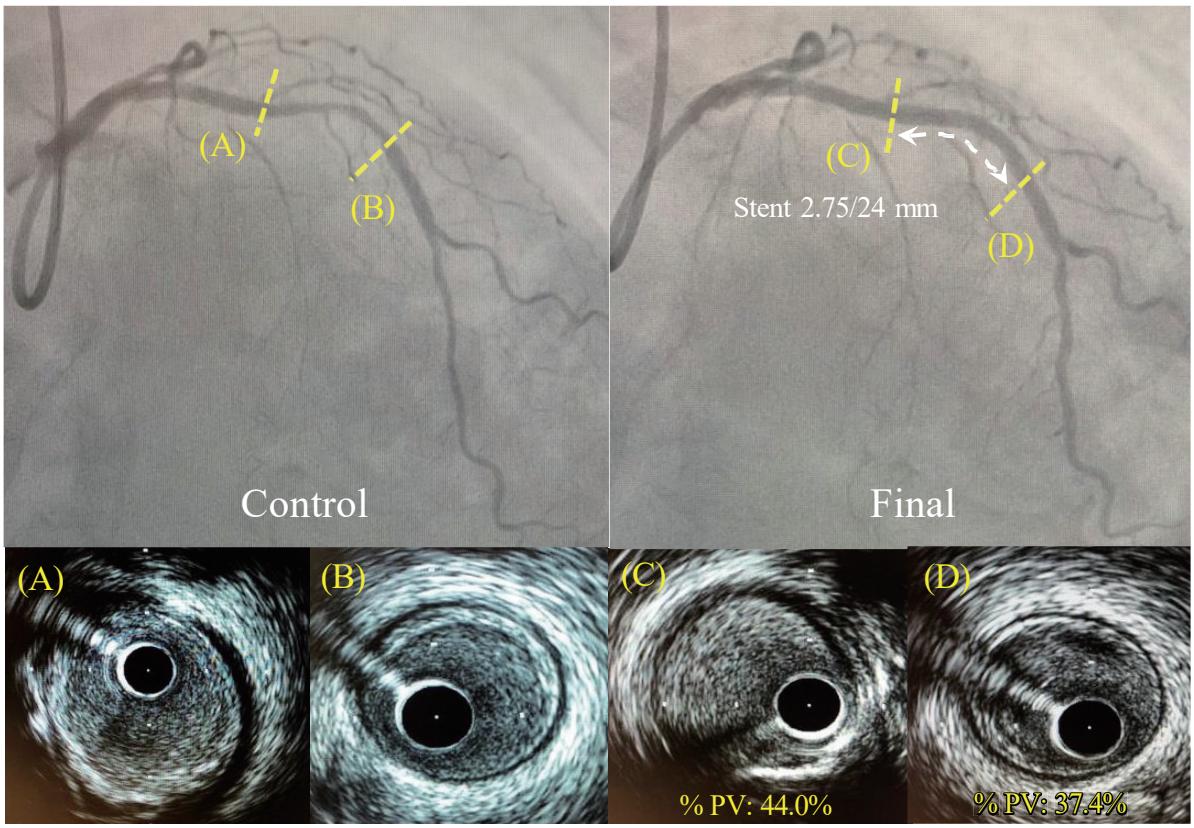


Fig. 5. Representative case treated with robotic-assisted PCI system
(A) IVUS image of proximal stent landing position.
(B) IVUS image of distal stent landing position.
(C) IVUS image of proximal stent edge position, %plaque volume was 44.0 %.
(D) IVUS image of distal stent edge position, %plaque volume was 37.4 %.

group, but not to a statistically significant extent (12.1% vs. 19.7%, p = 0.156).

A representative case subjected to R-PCI is illustrated in Figure 5. The patient in question, Case No. 144, was a 78-year-old man presenting with chronic coronary syndrome and concurrent comorbidities of hypertension, diabetes, and dyslipidemia. The intervention employed a robotic-assisted system. The lesion of concern manifested as a severe stenosis situated in the midsection of the left anterior descending artery, devoid of significant

Table 5. Clinical outcomes of Robotic PCI vs. Conventional PCI

| | (A) Baseline data | | | (B) Data after propensity score matching | | |
|---|---|---|---|---|---|---|
| | Robotic PCI (n = 105) Patients = 97 | Conventional PCI (n = 267) Patients = 212 | p value | Robotic PCI (Patients n = 91) | Conventional PCI (Patients n = 91) | p value |
| Procedure succusses, n (%) (Final TIMI = 3, % DS < 30) | 105 (100) | 259 (97) | 0.073 | 91 (100) | 91 (100) | 1.000 |
| Switching to manual operation, n (%) | 12 (11.4) | NA | NA | 11 (12.1) | NA | NA |
| PCI complication | | | | | | |
| Death, n (%) | 0 | 0 | NS | 0 | 0 | NS |
| Myocardial infarction, n (%) | 0 | 0 | NS | 0 | 0 | NS |
| Coronary bypass grafting, n (%) | 0 | 0 | NS | 0 | 0 | NS |
| No-flow / Slow-flow, n (%) | 0 | 6 (2.2) | 0.121 | 0 | 0 | NS |
| Distal embolization, n (%) | 2 (1.9) | 2 (0.7) | 0.331 | 1 (1.1) | 1 (1.1) | 1.000 |
| Side branch occlusion, n (%) | 1 (1.0) | 4 (1.5) | 0.681 | 1 (1.1) | 1 (1.1) | 1.000 |
| Coronary Perforation, n (%) | 0 | 0 | NS | 0 | 0 | NS |
| Stent thrombosis, n (%) | 0 | 0 | NS | 0 | 0 | NS |
| Stroke, n (%) | 0 | 0 | NS | - | - | - |
| Hemorrhagic complication, n (%) | 1 (1.0) | 1 (0.4) | 0.493 | 1 (1.1) | 0 | 0.316 |
| Contrast-associated AKI, n (%) | 4 (3.8) | 8 (3.0) | 0.689 | 3 (3.3) | 1 (1.1) | 0.312 |
| 30-day outcomes | | | | | | |
| Cardiovascular death, n (%) | 0 | 1 | 0.498 | 0 | 0 | NS |
| Myocardial infarction, n (%) | 0 | 1 | 0.498 | 0 | 0 | NS |
| Target lesion revascularization, n (%) | 0 | 0 | NS | 0 | 0 | NS |
| 1-year outcomes | | | | | | |
| Cardiovascular death, n (%) | 0 | 6 | 0.094 | 0 | 3 | 0.081 |
| Myocardial infarction, n (%) | 0 | 1 | 0.498 | 0 | 0 | NS |
| Target lesion revascularization, n (%) | 0 | 3 | 0.239 | 0 | 2 | 0.155 |

Procedure success defined as final angiographic coronary flow TIMI > 3, and % diameter stenosis >30% by quantitative coronary angiography. Contrast-associated Acute Kidney Injury (AKI) was defined as a serum creatinine level of 0.5 mg/dL greater or a 25% increase within 5 days after PCI. Hemorrhagic complications were defined as BARC3 or 5 bleeding, including vascular dissection, pseudoaneurysm, and arteriovenous fistula. NA, not available; NS, not significant.

calcification. A Sirolimus-eluting stent (2.75 / 24 mm) was deployed subsequent to pre-dilatation ballooning (2.5mm). The concluding therapeutic outcomes evidenced diminished contrast and radiation exposure metrics (fluoroscopy time = 15 min, total radiation exposure = 0.51 mSv, contrast dose = 40 ml), and IVUS assessment revealed an absence of stent malapposition.

The clinical outcomes of robotic PCI vs. conventional PCI are provided in Tables 5A and 5B. The procedural success rates were 100% in the R-PCI group and 97% in the C-PCI group (p = 0.073, refer to Table 5A). Switching to manual operation rate in the R-PCI group was 11.4%. There were no

significant differences in PCI complications such as distal embolization, side branch occlusion, and contract-associated acute kidney injury.

The post-R-PCI and C-PCI 30-day follow-up rates were 100%, and there were no incidences of death, cardiovascular events, or target lesion revascularization (TLR). During the 1-year follow-up in the C-PCI group, cardiovascular deaths occurred in 3 cases (Patient No. 27 died of sudden cardiac death 2 months after PCI, Patient No.51 had a history of transcatheter aortic valve replacement after PCI, died of sudden cardiac death 11 months after index PCI, and Patient No. 151 died of heart failure with renal dysfunction).

## IV. Discussion

The present study comprehensively compared robotic and conventional PCI groups to validate the effectiveness of the IVUS-guided robotic PCI. The following are the main findings obtained herein: (1) the median contrast dose (70.6 mL vs. 88.4 mL, $p < 0.001$), patient skin dose (0.7 Gy vs. 1.0 Gy, $p = 0.013$), and fluoroscopy time (19.5 min vs. 25.9 min, $p < 0.001$) were all significantly lower in the R-PCI group; (2) This cohort revealed an equal incidence of LGM following PCI in the R-PCI group (12.1% vs. 19.7%, $p = 0.156$); (3) During 30-day follow-up after index PCI, there were no incidences of death, cardiovascular events, or TLR. Cardiovascular death and all-cause death at 1year follow-up tended to be higher in the C-PCI group.

1. Safety of robotic PCI

In the present study, findings strongly indicate that R-PCI is associated with notable advantages in reducing contrast usage, lowering patient skin dose, and shortening fluoroscopy time when compared to C-PCI. This underscores the potential benefits of R-PCI in minimizing procedural risks.

In the previous study, 310 consecutive robotic PCI patients were compared with 686 propensity score-matched traditional PCI patients between 2017 and 2019 [4]. R-PCI was associated with a significant decrease in radiation exposure to the patient (cGycm2; 4734 [2695–7746] vs. 5746 [3751–7833]; $p = 0.003$) with no increase in fluoroscopy time (minutes; 5.51 [3.53–8.31] vs. 5.48 [3.31–9.37]; $p = 0.936$), as well as contrast utilization (mL; 130 [103–170] vs. 140 [100–180]; $p = 0.905$).

Notably, while previous studies focused on angiography-guided robotic PCI, our study introduced IVUS-guided robotic PCI. The incorporation of the robotic system in conjunction with a PCI operator well-versed in IVUS may have contributed to the reduction in patient radiation exposure and contrast dose.

Unlike conventional PCI, where the operator stands at a relatively distant position from the monitor (distance from operator to monitor: 120-180cm, measured in our catheterization room), robotic PCI allows devices to be brought in and positioned at a closer distance (distance from operator to monitor: 50-80cm) in a sitting position. The ability of the primary operator to make decisions on balloon and stent positioning from close proximity to the monitor likely played a role in minimizing radiation exposure and contrast dose.

In the case of R-PCI, radiation doses were meticulously measured in all instances

for post-marketing surveillance of the robotic system. This stringent monitoring suggests that the bedside operator may have inadvertently minimized exposure. While radiation exposure to the operator in the C-PCI group was not available, R-PCI demonstrated a drastic reduction (Table 2B, 0mSv [0-1.2]).

It is worth noting that radiation exposure to the assistant was higher (Table 2B, 28mSv [12-58]) than that to the operator, as reported previously [18]. In the case of R-PCI, the assistant needs to be close to the X-ray tube, so efforts should be made to reduce radiation exposure by keeping as much distance as possible while the operator is manipulating the robot. Given the necessity for the assistant to be in close proximity to the X-ray tube during R-PCI, efforts should be made to minimize radiation exposure by maintaining as much distance as possible while the operator manipulates the robot.

Short-term clinical outcomes following robotic PCI have been consistently excellent, with no observed Major Adverse Cardiovascular Events (MACE) in previous reports[18-20]. In this study, there were no instances of cardiovascular death or all-cause death in the R-PCI group at the 1-year mark, and the incidence of PCI complications was comparable.

The relatively high success rate can be attributed to the exclusion, in advance, of cases involving wire and device delivery failure, as well as the failure of the final IVUS evaluation (refer to Table 5A and Fig. 3).

In the Conventional PCI (C-PCI) group, three cardiovascular deaths were recorded (refer to Table 5B). However, it is important to note that the small number of cases and the lack of statistical power necessitate further validation with additional cases. Despite adjusting for age, gender, and lesion background through propensity score matching, potential bias may still exist due to the inclusion of cases treated with Transcatheter Aortic Valve Replacement (TAVR) after PCI and patients with cancer in the C-PCI group.

In 2020, Corindus, a Siemens company and a leading developer of vascular robotics, initiated the global launch of an innovative set of automated robotic movements within the technIQ™ Series, designed for the CorPath GRX System. The Rotate on Retract (RoR) system marked the pioneering robotic wire movement in the technIQ™ system, showcasing its potential to reduce wiring and procedural time.

The latest addition to technIQ™ introduces additional robotic movements, including automated wiring techniques (wiggle, spin) and device automation techniques (dotter), offering operators enhanced capabilities. The integration of these systems holds promise for safely treating complex lesions with shorter procedure times.

It is noteworthy that the IVUS catheter utilized in this study, namely the AltaView™ imaging catheter and OptiCross™ imaging catheter, was not compatible with the CorPath GRX System, necessitating manual operation during intravascular imaging.

Conversely, the Eagle Eye Platinum catheter™ is compatible with the currently available robotic arm. The adoption of the Eagle Eye Platinum catheter™ has the potential to mitigate complications and reduce procedure time associated with manual conversion for

other imaging catheters. It is important to highlight that, as of now, the IVUS system has not been integrated into the robotic PCI system. Consequently, it may not be strictly characterized as an IVUS-guided robotic PCI.

2. Longitudinal geographic miss (LGM) of robotic PCI

Previous reports have illustrated that LGM following PCI can lead to restenosis, target vessel revascularization (TVR), and myocardial infarction (MI). The term "geographic miss" originated in interventional cardiology, defining cases where radiation therapy did not adequately cover the intracoronary injured area [21]. Notably, late lumen loss was significantly higher in geographic miss edges than in the irradiated segment and uninjured edges, with a significantly elevated restenosis rate observed in the injured edges.

Since the introduction of first-generation drug-eluting stents, LGM has been described in cases where the entire length of the injured or stenotic segment was not fully covered by the total length of the sirolimus-eluting stent [22]. In this previous study, LGM occurred in 47.6% of all patients, and the 1-year TVR rates were 5.1% in the LGM group vs. 2.5% in the no-GM group ($p = 0.025$). There was a 3-fold increase in myocardial infarction rates associated with LGM (2.4% vs 0.8%; $p = 0.04$). Moreover, an optical coherence tomography study of everolimus-eluting stents showed that lipid plaque volume and minimum lumen area immediately after stent implantation were predictors of stent edge restenosis, suggesting the importance of reducing LGM in second-generation DES as well [23]. A robotic-assisted PCI system was developed to provide accurate device delivery and deployment. The PRECISE study was the first large-scale multicenter study evaluating the safety and feasibility of successful completion without conversion to manual procedure, and technical device success was achieved in 162/164 cases (98.8%). Bezerra et.al reported that robotic-assisted PCI exhibited a lower incidence of LGM when compared to manual PCI, 12.2% to 43.1%, respectively ($p < 0.0001$), with a reduction in MACE also being observed [7]. In our study, the incidence of LGM in the robotic PCI group was 12.1%, consistent with previous findings. Notably, prior studies defined LGM based on angiography, indicating cases where the entire length of the injured or stenotic segment was not fully covered by the total length of the stent. In contrast, our study introduces a new, more reliable definition employing IVUS and incorporating objective numerical criteria.

The CorPath GRX System (Siemens Healthineers, Forchheim, Germany) features a touchscreen interface that enables users to make precise 1 mm adjustments, particularly beneficial for stent positioning. This functionality allows for fine-tuning of the final stent landing position and has the potential to mitigate Longitudinal Geographic Miss (LGM). While our study did not reveal a statistically significant difference, it is important to note that our sample size calculations were based on a significant difference in LGM incidence between IVUS-guided R-PCI and C-PCI, requiring 363 patients in each group.

When sample size calculations were derived from previous angiography-guided studies, it was anticipated that 34 cases in each group would yield a significant difference. Consequently, enrolling 91 cases in both

groups for this study was deemed sufficient. However, the lack of a significant difference in our study is presumed to be attributed to the use of IVUS guidance instead of angiography guidance. Despite the reported withdrawal of Siemens Healthineers from the R-PCI field, limiting the opportunity to verify additional cases, we anticipate that this investigation will serve as a valuable reference for future research when an enhanced robotic system is developed.

The present study has some limitations. Firstly, despite the implementation of propensity score matching in our study, the retrospective nature of the trial may have introduced inherent biases and confounding factors, thereby limiting our ability to establish a definitive cause-and-effect relationship between the treatment methods and outcomes. Secondly, it is worth noting that the study might have lacked the statistical power necessary to detect smaller differences in LGM between the robot-assisted and conventional PCI groups. A more substantial sample size could contribute to more conclusive results. Thirdly, it is important to acknowledge that our study may not strictly qualify as an IVUS-guided robotic PCI. This is because the IVUS system has not been integrated into the robotic PCI system, and the manipulation of the IVUS catheter was conducted without utilizing the robotic system. Fourthly, we recognize that post-marketing surveillance could have inadvertently influenced the observed differences in contrast media and radiation dose, leading to lower values in the R-PCI group. This factor should be considered when interpreting the results.

In our investigation, we observed a noteworthy reduction in patient exposure to contrast and radiation in the IVUS-guided robotic-assisted PCI group, with concomitant modest improvement in cardiovascular outcomes. Furthermore, we found that the incidence of LGM remained consistent in the IVUS-guided setting.

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## References

1) **Serruys PW, de Jaegere P, Kiemeneij F, et al.**: A comparison of balloon-expandable-stent implantation with balloon angioplasty in patients with coronary artery disease. Benestent Study Group. N Engl J Med **331**, 489-495, 1994.
2) **Morice MC, Serruys PW, Sousa JE, et al.**: A randomized comparison of a sirolimus-eluting stent with a standard stent for coronary revascularization. N Engl J Med **346**, 1773-1780, 2002.
3) **Smitson CC, Ang L, Pourdjabbar A, et al.**: 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, 2018.
4) **Patel TM, Shah SC, Soni YY, et al.**: Comparison of robotic percutaneous coronary intervention with traditional percutaneous coronary intervention:

a propensity score-matched analysis of a large cohort. Circ Cardiovasc Interv **13**, https://doi.org/10.1161/CIRCINTERVENTIONS.119.008888, 2020.

5) **Campbell PT, Kruse KR, Kroll CR, et al.**: The impact of precise robotic lesion length measurement on stent length selection: ramifications for stent savings. Cardiovasc Revasc Med **16**, 348-350, 2015.
6) **Weisz G, Metzger DC, Caputo RP, et al.**: Safety and feasibility of robotic percutaneous coronary intervention: PRECISE (Percutaneous Robotically-Enhanced Coronary Intervention) Study. J Am Coll Cardiol **61**, 1596-1600, 2013.
7) **Bezerra HG, Mehanna E, W Vetrovec G, et al.**: Longitudinal Geographic Miss (LGM) in robotic assisted versus manual percutaneous coronary interventions. J Interv Cardiol **28**, 449-455, 2015.
8) **Kimura T, Koeda Y, Ishida M, et al.**: Safety and feasibility of intravascular ultrasound-guided robotic percutaneous coronary intervention. Coron Artery Dis **34**, 463–469, 2023.
9) **Metz JA, Yock PG** and **Fitzgerald PJ**: Intravascular ultrasound: basic interpretation. Cardiol Clin **15**, 1-15, 1997.
10) **Nissen SE** and **Yock P**: Intravascular ultrasound: novel pathophysiological insights and current clinical applications. Circulation **103**, 604-616, 2001.
11) **Morino Y, Tamiya S, Masuda N, et al.**: Intravascular ultrasound criteria for determination of optimal longitudinal positioning of sirolimus-eluting stents. Circ J **74**, 1609-1616, 2010.
12) **Jang JS, Song YJ, Kang W, et al.**: Intravascular ultrasound-guided implantation of drug-eluting stents to improve outcome: a meta-analysis. JACC Cardiovasc Interv **7**, 233-243, 2014.
13) **Russo RJ, Silva PD, Teirstein PS, et al.**: A randomized controlled trial of angiography versus intravascular ultrasound-directed bare-metal coronary stent placement (the AVID Trial). Circ Cardiovasc Interv **2**, 113-123, 2009.
14) **Claessen BE, Mehran R, Mintz GS, et al.**: Impact of intravascular ultrasound imaging on early and late clinical outcomes following percutaneous coronary intervention with drug-eluting stents. JACC Cardiovasc Interv **4**, 974-981, 2011.
15) **Räber L, Mintz GS, Koskinas KC, et al.**: Clinical use of intracoronary imaging. Part 1: guidance and optimization of coronary interventions. An expert consensus document of the European Association of Percutaneous Cardiovascular Interventions. Eur Heart J **39**, 3281-3300, 2018.
16) **Kobayashi N, Mintz GS, Witzenbichler B, et al.**: Prevalence, features, and prognostic importance of edge dissection after drug-eluting stent implantation: an ADAPT-DES intravascular ultrasound substudy. Circ Cardiovasc Interv **9**, https://doi.org/10.1161/CIRCINTERVENTIONS.115.003553, 2016.
17) **Suzuki N, Asano T, Nakazawa G, et al.**: Clinical expert consensus document on quantitative coronary angiography from the Japanese Association of Cardiovascular Intervention and Therapeutics. Cardiovasc Interv Ther **35**, 105-116, 2020.
18) **Kagiyama K, Mitsutake Y, Ueno T, et al.**: Successful introduction of robotic-assisted percutaneous coronary intervention system into Japanese clinical practice: a first-year survey at single center. Heart Vessels **36**, 955-964, 2021.
19) **Koeda Y, Ishida M, Sasaki K, et al.**: Periprocedural and 30-day outcomes of robotic-assisted percutaneous coronary intervention used in the intravascular imaging guidance. Cardiovasc Interv Ther **38**, 39-48, 2023.
20) **Mahmud E, Naghi J, Ang L, et al.**: Demonstration of the safety and feasibility of robotically assisted percutaneous coronary intervention in complex coronary lesions: results of the CORA-PCI Study (Complex Robotically Assisted Percutaneous Coronary Intervention). JACC Cardiovasc Interv **10**, 1320-1327, 2017.
21) **Sabaté M, Costa MA, Kozuma K, et al.**: Geographic miss: a cause of treatment failure in radio-oncology applied to intracoronary radiation therapy. Circulation **101**, 2467-2471, 2000.
22) **Costa MA, Angiolillo DJ, Tannenbaum M, et al.**: Impact of stent deployment procedural factors on long-term effectiveness and safety of sirolimus-eluting stents (final results of the multicenter prospective STLLR trial). Am J Cardiol **101**, 1704-1711, 2008.
23) **Ino Y, Kubo T, Matsuo Y, et al.**: Optical coherence tomography predictors for edge restenosis after everolimus-eluting stent implantation. Circ Cardiovasc Interv **9**. https://doi.org/10.1161/CIRCINTERVENTIONS.116.004231, 2016.

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# 血管内超音波（IVUS）ガイドを使用した ロボット支援および従来の手動による 経皮的冠動脈形成術（PCI）の比較研究

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要旨

従来の研究では，血管造影ガイドのロボット支援 PCI（R-PCI）が，従来の手動 PCI（C-PCI）と比較して, 放射線被曝, 造影剤使用量が低いと示唆されている. 本研究では，IVUS ガイダンスを使用した R-PCI と C-PCI の安全性を評価した. 2019 年から 2021 年までに，当院で合計 807 回の PCI 手術が施行された．両グループ間の患者背景および病変特性の調整のために，傾向スコアマッチング分析を行った（各 91 例）．主要評価項目は造影剤使用量，皮膚被曝，および全透視時間とし，二次評価項目は 30 日および 1 年の心血管事象とした . 造影剤量（$p < 0.001$），患者の皮膚被曝（$p = 0.013$），および全透視時間（$p < 0.001$）は, すべて R-PCI グループで有意に低かった．R-PCI グループでは 30 日の心血管イベントはなく，1 年後の心血管死亡率は C-PCI グループよりも低い傾向だった（$p = 0.082$）．IVUS ガイダンスでのロボット支援 PCI グループでは，造影剤および放射線への患者の被曝が有意に低く，心血管のアウトカムも良好だった.