Safety Assessment of Coronary Arteries During Left Bundle Branch Area Pacing

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Abstract

Objective: This study aimed to investigate the relationship between the location of implantation of the Left Bundle Branch Area Pacing (LBBAP) electrode and the coronary artery and to assess the safety of LBBAP surgery. **Methods:** Patients who underwent the LBBAP procedure and coronary angiography (CAG) at the Second Affiliated Hospital of Nanchang University between January 1, 2019 to October 1, 2020 were included. We read the patient's LBBAP and CAG imaging data and used the nine-partition method to measure the vertical distance from the tip of the pacing electrode to each coronary artery in multiple projection positions during the ventricular systolic period. Changes in the ST-T segment in the electrocardiogram, serum troponin and myocardial enzyme profiles were observed before and after the LBBAP surgery. **Results:** Overall, 50 patients were evaluated. The average vertical distances from the electrode tip to the left anterior descending branch (LAD), right posterior coronal descending branch (PD), left posterior ventricular branch (PL) were 19.69±8.72 mm, 26.09±8.02 mm, and 21.11±7.86 mm, respectively. The minimum were 5.28 mm, 9.51 mm and 8.69 mm, respectively. CAG in all patients showed no significant injury to the ventricular septal branch. And there were no elevated serum troponin or cardiac enzyme profiles. **Conclusions:** This study suggested that the coronary arteries were safest when the LBBAP electrodes were placed within a rectangle formed by the PM, M, PI, and MI center points. The PM was the ideal position to implant the LBBAP electrodes, which had a low risk of coronary vascular injury.

1 INTRODUCTION

Currently, the pacing methods mainly used in clinical treatment include right ventricular pacing (RVP), His bundle pacing (HBP) and LBBAP. Among them, LBBAP is a new physiological pacing method that can effectively narrow the width of the QRS wave, synchronize mechanical contraction of the left ventricular myocardium, improve cardiac function, and overcome atrial fibrillation defects and heart failure caused by RVP pacing[1]. However, LBBAP electrodes should permeate from the right ventricular septum to the left ventricular septum subendocardium. Therefore, there is a potential risk of damaging the coronary arteries and veins, such as the ventricular septal, the left anterior descending branch (LAD), the right posterior coronal descending branch (PD) and the left posterior ventricular branch (PL) during the implantation of LBBAP electrodes. Furthermore, during the LBBAP procedure, Qi P et al.[2] found that the pacemaker electrode penetrated the interventricular septal vessels which were successfully visualized upon injecting the contrast medium into the C315 His sheath. In the previous reports, pacemakers implanted in the interventricular septum can damage the anterior descending artery or interventricular septal artery. For example, some studies have found that ventricular septal pacing electrodes can compress the anterior descending artery to different degrees, resulting in different degrees of myocardial infarction[3-6]. However, to our knowledge, there are no studies concerning LBBAP electrodes and coronary vascular injury. Therefore, this study aimed to evaluate the risk of intraoperative coronary injury by measuring the adjacency relationship between the tip of

LBBAP electrodes and the coronary arteries to provide a reliable clinical reference for the safe implantation of the LBBAP.

2 METHODS

2.1 Inclusion and exclusion criteria

This study collected the imaging information and data from inpatients who underwent the LBBAP procedure and CAG in the Center of Cardiovascular Medicine, the Second Affiliated Hospital of Nanchang University between January 1, 2019 and October 1, 2020. The exclusion criterion was patients with one or more of the following diseases: a) acute myocardial infarction; b)intracoronary stenting; c) chronic occlusive disease of the coronary arteries. This study was approved by the local ethical board and was performed in accordance with the Declaration of Helsinki.

2.2 LBBAP surgery

In this study, all the pacemaker implantations were performed through the left subclavian vein or the left axillary vein. During surgery, a C315 His sheath was inserted into the tricuspid ring using a J-wire. In the right anterior oblique position (RAO), the pacemaker electrode (Model 3830, 69 cm, Medtronic Inc., Minneapolis, MN) was pushed forward through the sheath, with the distal screw located at the tip of the catheter. First, the His potential was marked, and the tip of the pacing lead was moved downward and forward in the ventricular direction for approximately 1.5-2 cm. Subsequently, the optimal pacing site was determined by the following criteria: a) the pacing QRS interval was less than 145 ms in the V1 lead, or the QRS wave had a “W” incisura in the V1 lead; b) the left anterior oblique position confirmed that the tip of the pacing lead reached the left ventricular septum intima; c) recording to the left bundle branch potential (from scratch and small to large); d) the pacing pattern gradually changes from the LBBB to the RBBB pattern[7]. Finally, the electrode was fixed and connected to the pacemaker using the screws. In this study, we detected the pacing threshold, recorded the left bundle branch potential, monitored the pacing impedance, and conducted 12-lead concurrent electrocardiography during the surgeries.

2.3 Recording the pacing electrode position

Two nonsurgical doctors independently read the patient’s image data and recorded the distribution position of the pacing electrode using the nine partition method[8]. As shown in Figure 1, with the fluoroscopy guidance, the ventricles in RAO 30° were divided into three equal parts, along the long axis and short axis and divided into nine regions. From left to right and from top to bottom, the ventricles were marked as PS, MS, AS, PM, M, AM, PI, MI and AI. We observed and recorded the pacing electrode site in the nine regions using a two dimensional projection position.

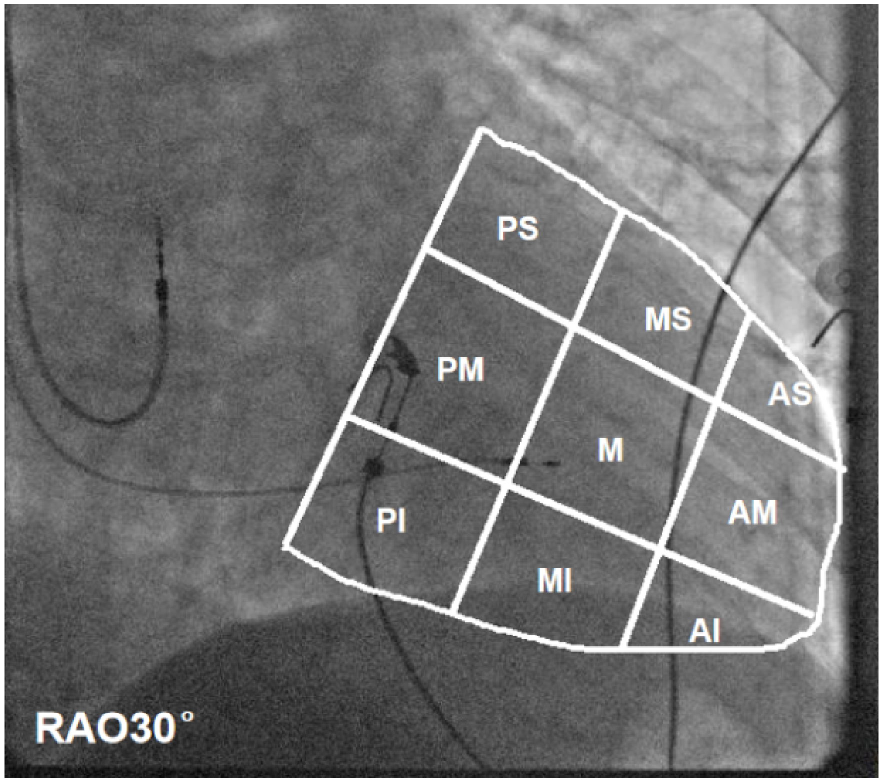

Figure 1 Distribution of nine partition method in fluoroscopy at right anterior oblique (RAO) 30°. PS = posterior superior, MS = middle superior, AS = anterior superior, PM = posterior median, M = median, AM = anterior median, PI = posterior inferior, MI = middle inferior, AI = anterior inferior.

2.4 Measuring the distance between the pacing electrode and the coronary artery

As shown in Figure 2, using a Beijing Sichuang technology system, we measured the vertical distance from the tip of the pacing electrode to the anterior descending artery during systole, with the positive head position (AP + CRA 30°), foot position (AP + CAU 30°), left shoulder position (LAO 30° + CRA 20°) and spider position (LAO 45° + CAU 30 °). The maximum value was recorded, which was closest to the actual spatial distance between the tip of the pacing electrode and the anterior descending artery. The measurement results are represent using two decimal places. The same method was used to measure the distance from the tip of the pacing electrode to the posterior descending branch of the right coronary artery and to the posterior branch of the left ventricle.

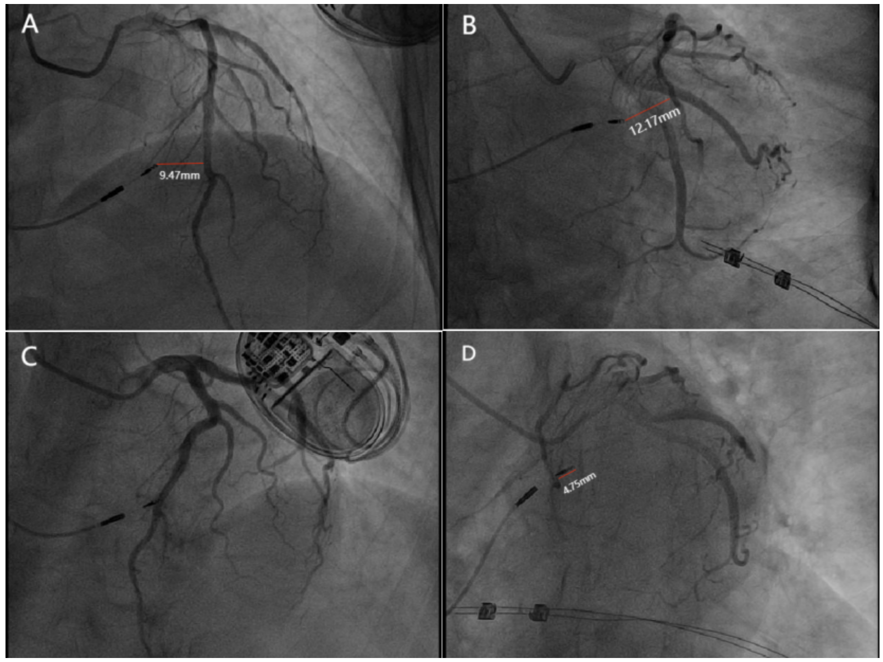

Figure 2 Vertical distance from the tip of the pacing electrode to the anterior descending branch during systole. (A) AP + CRA 30° 47 mm in fluoroscopy. (B) AP + CAU 30° 17 mm in fluoroscopy. (C) LAO 30° + CRA 20° in fluoroscopy (the tip of the pacing electrode overlaps with the anterior descending branch, so the vertical distance is measured as 0 mm). (D) LAO 45° + CAU 30° 75 mm in fluoroscopy. The maximum distance is 12.17 mm.

2.5 Observing the coronary vascular injury

Intraoperative intrathecal angiography of C315 His was performed to observe the damage to the coronary arteries, such as the ventricular septal branch.

2.6 Observing the perioperative myocardial injury and the other complications

At LAO 45°, we observed whether the patient developed acute cardiac tamponade and followed changes in their condition within 24h after LBBAP surgery. Simultaneously, before and after pacemaker implantation, the patients underwent electrocardiography and serum troponin and myocardial enzyme spectrum detection to observe whether the implanted pacing electrode damaged the blood vessels of heart, resulting in myocardial ischemia and myocardial infarction.

2.7 Statistical analysis

IBM SPSS Statistics software (version 20) was utilized to analyze the data. For checking the normality test of the data, the F-test or the t-test was used for the data in accordance with normal distribution; otherwise, the Kruskal-Wallis test was used. Two tailed $P< 0.05$ was set as statistical significance. The distance from the pacing electrode to the coronary artery was calculated as the mean ± standard deviation.

3 RESULTS

3.1 Baseline characteristics

We selected 139 patients who underwent the LBBAP in our hospital between January 2019 and October 2020. Among them, 89 patients with acute myocardial infarction and previous cardiac stent implantation were excluded, leaving 50 patients (27 men) for analysis. As shown in Table 1, 38 patients had atrioventricular block, 4 had sinus syndrome, 4 had ventricular tachycardia, 8 had dilated cardiomyopathy and 4 had hypertrophic cardiomyopathy. The QRS interval after the LBBAP procedure was significantly shorter than that before the procedure(124.9 ± 32.6ms vs 113.4 ± 17.1ms, $P<0.05$).

Table 1 Baseline characteristics of patients.

Participants	Participants		
Age (year)	Age (year)	71.4±9.9	71.4±9.9
Men	Men	27(54%)	27(54%)
Atrioventricular block	Atrioventricular block	38(76%)	38(76%)
Sick sinus syndrome	Sick sinus syndrome	4(8%)	4(8%)
Dilated cardiomyopathy	Dilated cardiomyopathy	8(16%)	8(16%)
Hypertrophic cardiomyopathy	Hypertrophic cardiomyopathy	4(8%)	4(8%)
Ventricular tachycardia	Ventricular tachycardia	4(8%)	4(8%)
Coronary atherosclerosis	Coronary atherosclerosis	14(28%)	14(28%)
Heart failure	13(26%)	13(26%)	
Hypertension	33(66%)	33(66%)	
Diabetes	11(22%)	11(22%)	
Chronic renal insufficiency	4(8%)	4(8%)	
Old cerebral infarction	7(14%)	7(14%)	
Preoperative LVEF(%)	58.8±13.9	58.8±13.9	
Interventricular septal thickness(mm)	10.5±1.7	10.5±1.7	
Left ventricular posterior wall thickness(mm)	9.8±1.3	9.8±1.3	
Right ventricular posterior wall thickness(mm)	4.1±0.4	4.1±0.4	
Preoperative QRS interval(ms)	124.9±32.6	124.9±32.6	
Postoperative QRS interval(ms)	113.4±17.1	113.4±17.1	
DDD	40(80%)	40(80%)	
ICD	4(8%)	4(8%)	
VVIR	4(8%)	4(8%)	
CRT	2(4%)	2(4%)	

LVEF = left ventricular ejection fraction; DDD = dual chamber pacemaker; ICD = implantable cardioverter-defibrillator; CRT = cardiac resynchronization therapy.

3.2 Distribution position of the pacing electrodes in the nine partition method

As shown in Figure 3, at RAO 30°, the red dots represent the two-dimensional distribution of the tips of the LBBAP electrodes in 50 patients. Among these, 28 pacing electrodes were in the PM position, 14 in the M position, 5 in the PI position, and 3 in the MI position. All pacing electrodes were located in the PM, M, PI and MI positions or in the junction area. Overall, 84% of the electrodes were located in the PM and M positions, and the pacing electrodes were densely distributed in the PM position.

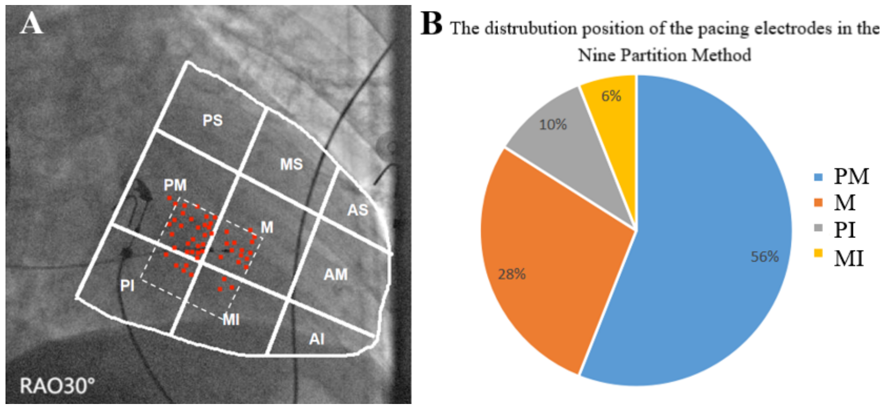

Figure 3 (A) At RAO 30°, the red dots represent the two-dimensional distribution of the tips of the LBBAP electrodes, and the white dotted rectangle is composed of the central points of the PM, M, PI and MI positions. (B) Pie chart of the distribution of the electrodes in each position.

3.3 Vertical distance from the tip of the pacing electrode to the coronary artery

Tables 2.1 and 2.2 show the vertical distances from the end-systolic LBBAP pacing electrode to the branches of the coronary artery. The average distance from the tip of the pacing electrode to the anterior descending branch was shorter than that to the posterior descending branch (19.69 ± 8.72 mm) vs (26. 09 8 ± 02mm). The mean distance from the electrode tip to the left ventricular posterior branch of the right coronary artery (21.11 ± 7.86 mm) was similar to the average distance to the anterior descending branch. This suggests a higher risk of damage to the anterior descending branches and a lower risk of damage to the posterior descending branches. In addition, the minimum distances from the tip of the electrode to the anterior descending branch, posterior descending branch and left ventricular posterior branches were 5.28 mm, 9.51 mm and 8.69 mm, respectively, and the maximum distances were 43.07 mm, 44.11 mm and 42.50 mm, respectively. The ranges of the distance were 37.79 mm, 34.60 mm and 33.81 mm, respectively.

Table 2.1 Vertical distance from the electrode tip in LBBAP to each coronary artery.

Coronary artery	Average (mm)	SD	Min(mm)	Max(mm)	Range(mm)
LAD	19.69	8.72	5.28	43.07	37.79
PD	26.09	8.02	9.51	44.11	34.60
PL	21.11	7.86	8.69	42.50	33.81

SD = standard deviation; Min = minimum; Max = maximum; LAD = left anterior descending branch; PD = right posterior coronal descending branch; PL = left posterior ventricular branch.

Table 2.2 Distance from the electrode tip of the different position to each coronary artery.

	Mean(mm)	SD
Distance from the electrode to the LAD	Distance from the electrode to the LAD	Distance from the electrode to the LA
PM	21.21	9.66
M	15.20	6.61
PI	21.25	3.58
MI	23.82	9.43
Distance from the electrode to the PD	Distance from the electrode to the PD	Distance from the electrode to the PD
PM	28.47	7.67
M	24.76	6.87

PI	18.96	10.74
MI	22.02	1.47
Distance from the electrode to the PL	Distance from the electrode to the PL	Distance from the electrode to the PL
PM	23.82	7.64
M	19.06	7.67
PI	14.60	5.26
MI	16.21	3.93

PM = posterior median; M = median; PI = posterior inferior; MI = middle inferior.

3.4 C315 His intrathecal angiography to visualize cardiovascular vascular injury

As shown in Figure 4, 38 (76%) patients underwent intrathecal angiography, and no ventricular septal artery development or hematoma formation was observed.

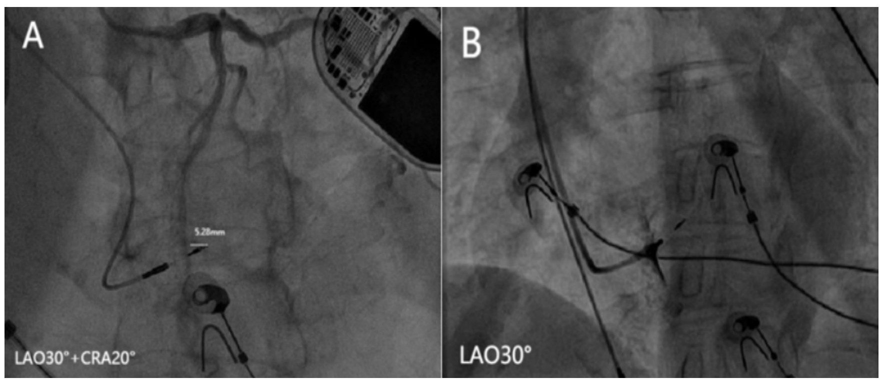

Figure 4 Image of the closest distance of the tip of the pacing electrode to the coronary artery. (A) Distance from the tip of the electrode to the anterior descending artery 5.28 mm. (B) C315 His intrathecal angiography shows no vascular scintigraphy.

3.5 Perioperative myocardial injury

3.5.1 Electrocardiogram

In patients with sick sinuses syndrome (implanted dual chamber pacemakers), the 24-h postoperative ECG showed no significant changes in the ST segment and T wave (Figure 5), indicating that the implanted pacing electrode did not cause obvious ischemic and infarction damage to the cardiovascular vessels.

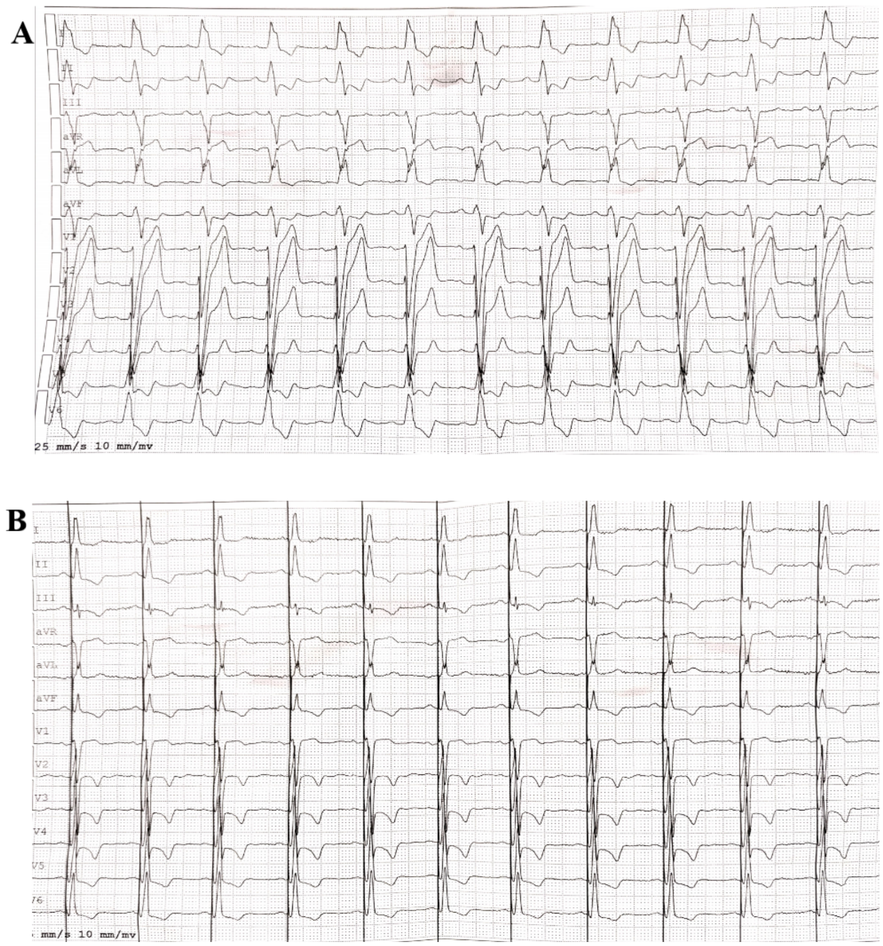

Figure 5 (A) Preoperative ECG of the patient with LBBAP. (B) Postoperative ECG of the patient with LBBAP.

3.5.2 Serum markers of myocardial injury

Compared with the preoperative period, serum troponin levels in postoperative patients increased to varying degrees but did not reach the level of observed in patients with myocardial infarction; moreover, there was no significant change in the postoperative myocardial enzyme profile. This indicated that the implantation of the LBBAP pacing electrode could damage the coronary veins and some small blood vessels of the heart or myocardial tissue, but without obvious myocardial ischemia or infarction (Table 3).

Table 3 Markers of serum myocardial injury before and after pacemaker implantation.

	Preoperatively	Postoperatively	P
Troponin(ng/ml)	0.034	0.8	0.1442
CK(U/L)	83.37	87.272	0.8598
CK-MB(ng/ml)	16.2	15.07	0.4456
LDH(U/L)	179.5	177.558	0.9206
MB(ng/ml)	112.34	92.04	0.5204

CK = creatine Kinase; CK-MB = creatine kinase isoenzymes; LDH = lactate dehydrogenase; MB = myoglobin.

3.6 Other complications

CAG examination in all patients showed no compression of the anterior descending, posterior descending, and posterior left ventricular arteries by the LBBAP electrodes. The contrast agent through the arterial vessels did not penetrate the pacing electrode. There were no complications, such as acute chest tightness, chest pain, angina pectoris, acute myocardial infarction, cardiac tamponade, or broken pacing electrodes during and within 24 h after surgery.

4 DISCUSSION

LBBAP is the most consistent with physiological pacing[7][9, 10], because the distribution of the pacing electrode is consistent with the anatomical and physiological walking of the left bundle branch, but it still lacks a specific electrode safe pacing range. This study not only measured the specific distance from the pacing electrode to each coronary artery, but also provided a safe pacing range for the pacing electrode. Due to the beam hardening and motion artifacts of metal pacing electrodes in cardiac computed tomography, the accuracy of the measurement accuracy is easily affected[11]. At the same time, Becker et al.[4] reported that the period when the electrode compressed the coronary arteries was the systolic phase. Therefore, systolic CAG was used for analysis in this study.

This study found that the average distance from the tip of the median electrode to the anterior descending branch was the smallest, and the average distance from the electrode to the anterior descending branch was similar in other positions, suggesting that the risk of damage to the anterior descending branch by pacing electrodes was highest in the median position. This is similar to the average distance (18.9 mm) measured by Pang B et al.[12] using cardiac computed tomography in patients with RVP. This study also found that the average distance from the tip of the PI to the posterior descending branch and the posterior branch of the left ventricle was the smallest, and the average distance from the tip of the PM electrode to the posterior descending branch and the posterior branch of the left ventricle was the largest, suggesting that the posterior descending electrode and the posterior branch of the left ventricle were at the highest risk of injury from the PI electrode. In summary, the distance from the PM electrode to each of the coronary arteries was always at its maximum, suggesting that this is a safe pacing electrode location.

In addition, LBBAP electrodes are at increased risk of damage to the ventricular septal branch on the basis of their anatomical site. Previously, Qi P et al.[2] found that ventricular septal vessels were developed during the injection of a contrast agent into the C315 His sheath to assess the depth of electrode implantation in LBBAP surgery. In addition, it may be a coronary venous vessel. Therefore, in this study, intrathecal angiography of C315 His was used to observe the damage to the ventricular septal branch. Although 38 patients underwent intrathecal angiography, no development of the ventricular septal artery or hematoma formation was observed. As the diameter, length, number and distribution of the anterior and posterior ventricular septal branches observed in each position vary from person to person, they are extremely inconsistent. Therefore, we were unable to measure the precise distance from the tip of the electrode to a certain anterior or posterior ventricular septal branch. It was impossible to quantify the risk of injury to the ventricular septal branch. However, it is recommended that intrathecal angiography with CAG should be completed during the LBBAP surgery to identify the damage to the ventricular septal branches.

Apart from this, anatomical abnormalities in the coronary arteries may be more likely to cause blood vessels to be damaged by pacing electrodes[13]. Pacing electrodes are more likely to damage the arterial blood vessels in patients with myocardial bridges. In this study, coronary angiography of 5 patients showed that the anterior descending artery had different degrees of myocardial bridging phenomenon, as shown in Figure 6. Myocardial fibers compressed the anterior descending artery during systole, and the blood flow of the arterial vessels returned to normal during diastole, which should be distinguished from the compression of the anterior descending artery by the pacing electrode. From multiple angles, there was no compression of the tip of the pacing electrode in the coronary artery of the myocardial bridge during systole. Moreover, there was no obvious chest tightness or chest pain, dynamic ST-T changes in the ECG, and no elevated markers of myocardial injury during or after surgery.

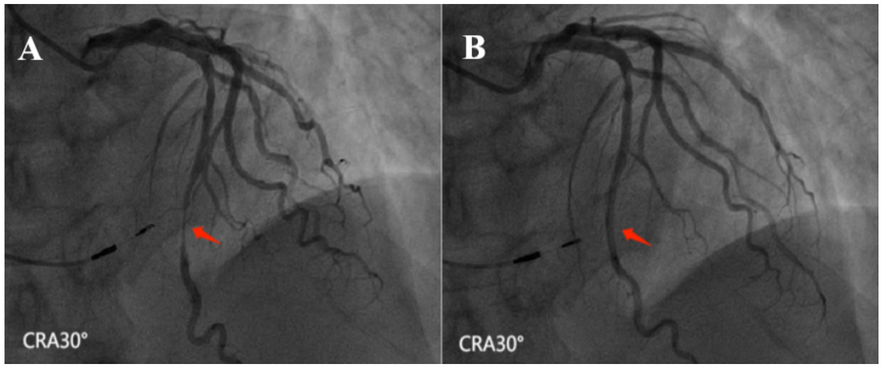

Figure 6 Red arrow indicates the myocardial bridge. (A) The middle segment of the anterior descending branch is compressed by myocardial fibers during systolic. (B) There is no compression of the anterior descending artery during diastole and the blood flow is unobstructed.

This study had some limitations. First, the veins that accompany the interventricular septal branch, the anterior descending branch and the posterior descending branch are difficult to detect by CAG when they injured by pacing electrodes[14]. Second, the damage to some small blood vessels of the heart is difficult to cause changes in serum troponin, myocardial enzyme profile and ST-T segment of the ECG[14]. It is not convenient for endurance exercise to increase cardiac troponin[15]. Third, because of the influence of anatomy and physiology, the distribution of electrodes in each of the nine partition positions is not well-proportioned, and the number of pacing electrodes in some positions is small. Therefore, it is necessary to increase the number of cases in further studies. Finally, in this study, the distance between the tip of the pacing electrode and the coronary artery was a rough estimate measured by fluoroscopy, which cannot be equivalent to the actual spatial distance. How to measure the accurate distance between the pacing electrode and the coronary artery is worthy of further study.

5 CONCLUSIONS

This study shows that the LBBAP electrode can be safely paced over a wide range. At RAO 30°, the pacing electrode located in the rectangle formed by connecting the central points of the PM, M, PI and MI is safe for the coronary artery. Locating the electrode in the PM position can not only quickly capture the left bundle branch, but also improve the safety of the coronary artery. The risk of anterior descending branch injury was greater than posterior descending branch injury.

ACKNOWLEDGMENT

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DATA AVAILABLITY STATEMENT

The data that support the findings of this study are available from the correspongding author upon reasonable request.

CONFILT OF INTERESTS

The authors declare that there is no actual or perceived potential conflict of interests.

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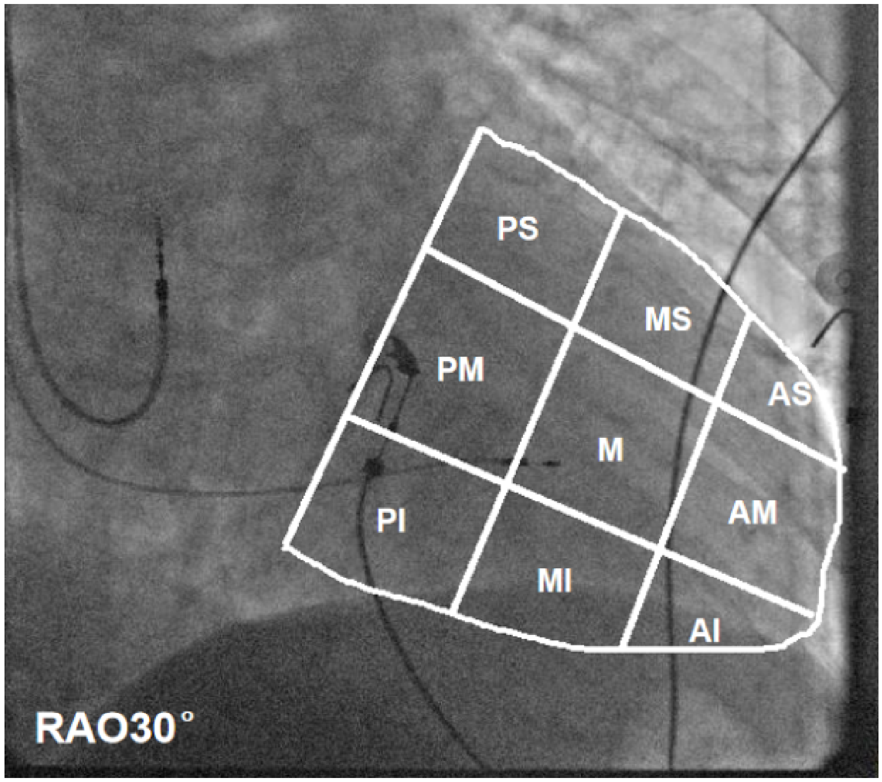
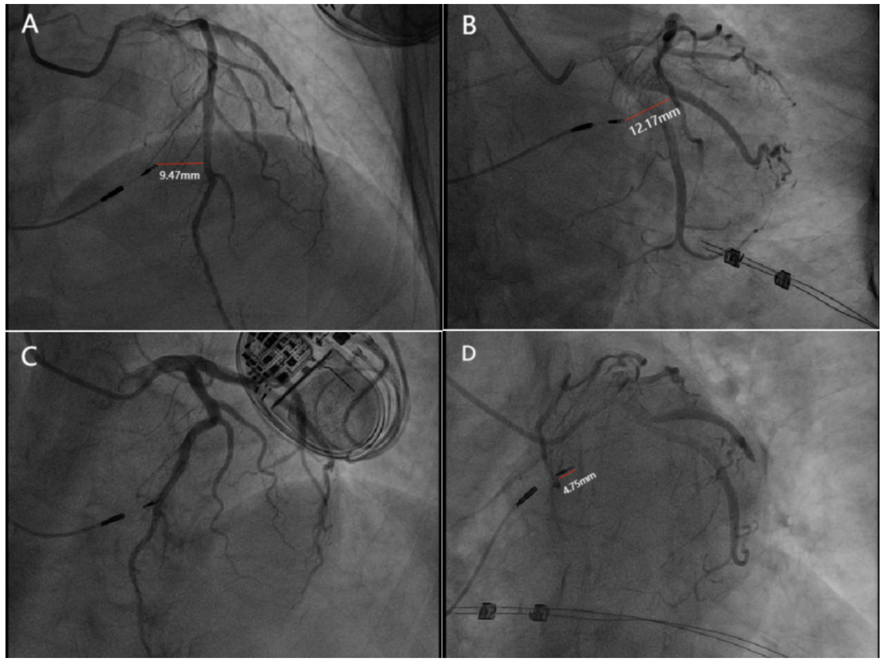
Nonstandard abbreviations and acronyms

AP	Anterior descending artery
RAO 30°	Right anterior oblique 30°projection position
CRA30°	Positive head position
CAU30°	Foot position
LAO30° + CRA20°	Left shoulder position
LAO45° + CAU30°	Spider position
LAD	Left anterior descending branch
PD	Right posterior coronal descending branch
PL	Left posterior ventricular branch
PS	Posterior superior
MS	Middle superior
AS	Anterior superior
PM	Posterior median
M	Median

AM	Anterior median
PI	Posterior inferior
MI	Middle inferior
AI	Anterior inferior
SD	Standard deviation

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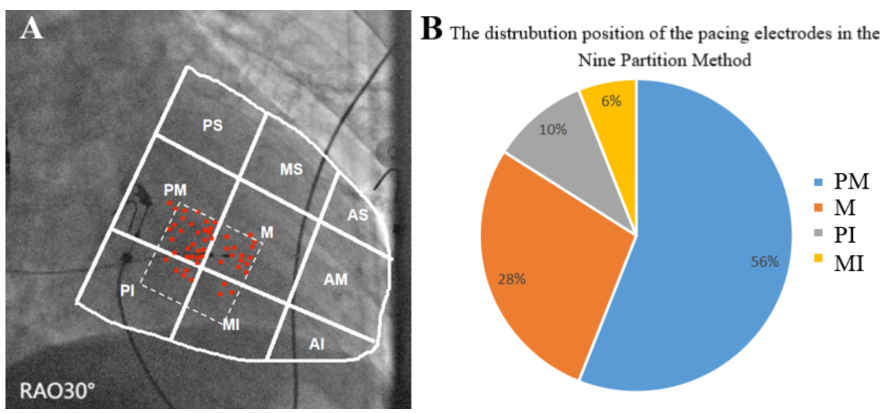
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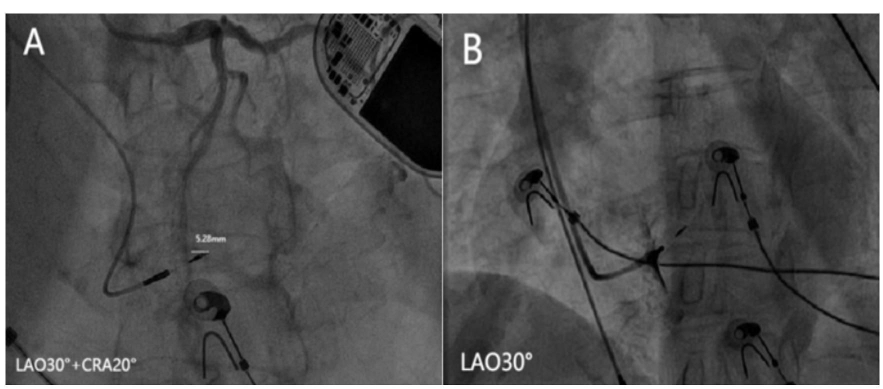
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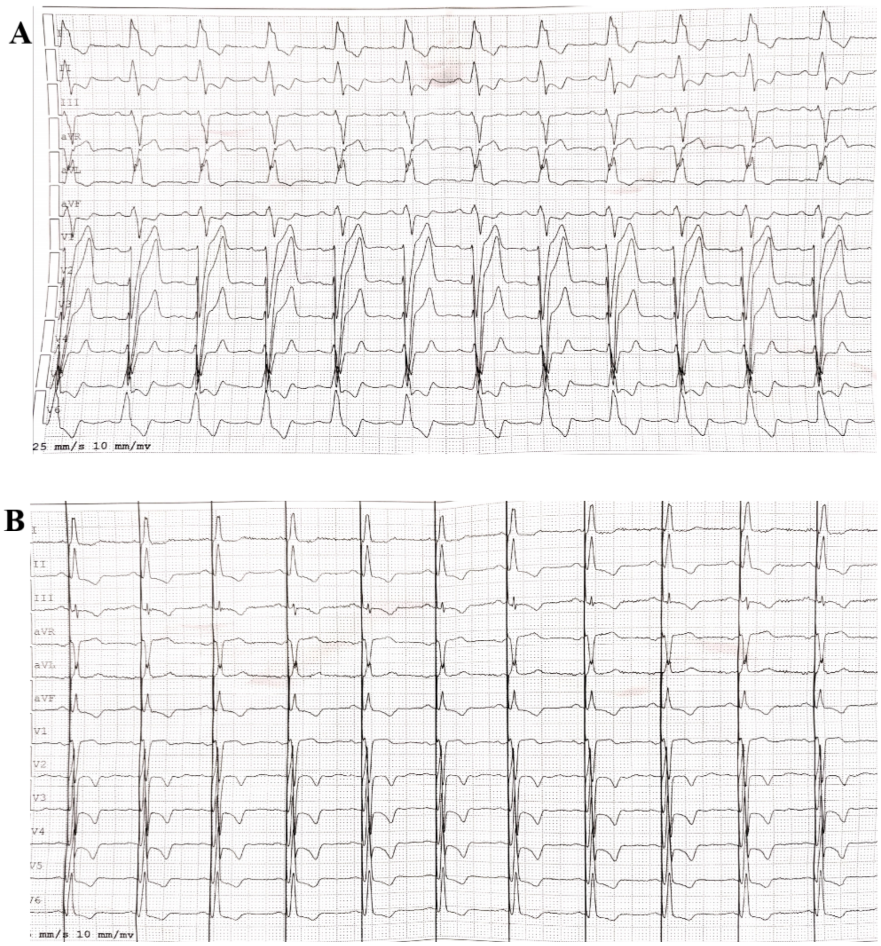
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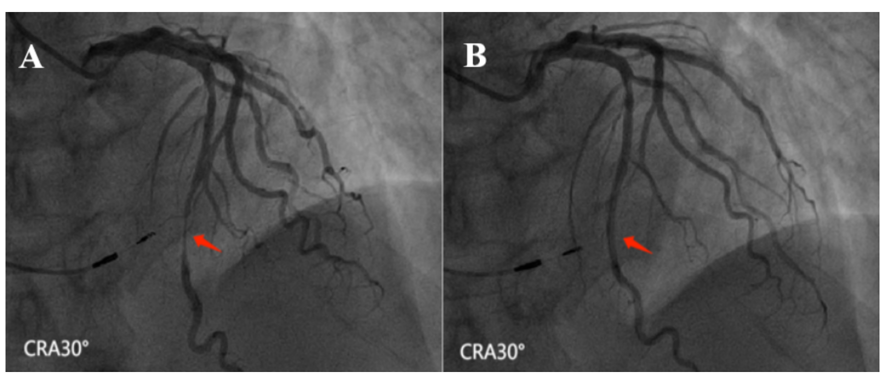
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