A Study to Analyze the Feasibility and Effectiveness of Left Bundle Branch Area Pacing Used in Young Children

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Abstract

Objective

This study was performed to investigate the feasibility and effectiveness of left bundle branch area pacing (LBBaP) used in young children.

Methods

From September 2020 to May 2021, total of thirty-one children (≤ 7 years old) with complete atrioventricular block were included. All patients were intended to receive the operation of LBBaP. The pacing parameters, cardiac function and cardiac synchrony were evaluated during follow-up.

Results

LBBaP succeeded in twenty-two children (3.3 ± 2.1 years old), with a success rate of 70.9%. LBBaP had failed in nine children, these children received right ventricular septal pacing (RVSP) eventually. The average postoperative QRS duration in patients of LBBaP group was narrower than that of RVSP group: 100.9 ± 9.1 versus 114.2 ± 11.9 ms ($P = 0.002$). The median time of follow-up was 12 (IQR 6–15) months. At last time of follow-up, the capture threshold of ventricular electrode in patients of LBBaP group were significantly lower than that of RVSP group (0.70 ± 0.25 versus 1.39 ± 0.94 V, $P = 0.011$). The echo-LVEF in patients of LBBaP group were better than that of RVSP group (66.1 ± 3.3 versus 63.1 ± 2.2%, $P = 0.025$). Additionally, the intraventricular and interventricular synchrony parameters in patients of LBBaP group were better than that of RVSP group: the standard deviation of time to peak strain (38.1 ± 5.3 versus 50.3 ± 7.0 ms, $P = 0.000$) and the interventricular mechanical delay time (38.4 ± 19.9 versus 65.0 ± 31.1 ms, $P = 0.012$) respectively.

Conclusion

LBBaP could be safely and effectively for young children. Satisfactory pacing parameters, narrow QRS duration and well cardiac synchrony parameters could be obtained.

Introduction

Pacemaker implantation is an important treatment for children with bradyarrhythmia. In the past, right ventricular apical pacing (RVAP) had been widely adopted. Studies proved that long-term RVAP would lead to cardiac dysfunction with the incidence of 5.9 to 19.1% [1–3]. Recently, with the renewal of concept and the development of technology, the operation of left bundle branch area pacing (LBBaP) has begun to perform in adult patients. Evidences showed that the LBBaP could avoid or even reverse cardiac dysfunction, and the result of long-term follow-up is safe and effective [4, 5]. However, there is still few data on available related to the application of LBBaP performing in children. Studies had reported some cases in adolescents, but there is no data referred to young children. This article aims to evaluate the feasibility, safety and effectiveness of LBBaP used in young children.

Methods

1.Patients

From September 2020 to May 2021, total of 31 young children (≤ 7 years old) with complete atrioventricular block were hospitalized at the Heart Center of the First Affiliated Hospital of Tsinghua University. All these children met the indications for permanent pacemaker implantation [6].

All procedures in this study involving human participants were performed in accordance with the ethical standards of the institution and the Helsinki Declaration of 1975. This study was approved by the ethics committee of our hospital (Ethics Document Batch Number: 202003).

2.Surgical Procedures

Material (Medtronic, USA): The type of “5076” active fixed electrode (length of 52cm) was selected as the atrial electrode. The type of “3830” electrode (length of 59cm or 69cm) was selected as the ventricular electrode. The different length of ventricular electrode was selected according to patient’s body size. Additionally, the type of “C315-S4” delivery sheath was used for assisting ventricular electrode implantation.

Every patient was given an informed consent form and an anesthesia consent form. Consent forms had been signed by patient’s guardian before pacemaker implantation. General anesthesia was performed during the operation.

The implantation of atrial electrode: According to the conventional method, the atrial electrode was placed in the position of right atrial appendage [7].

The implantation of ventricular electrode: The left axillary vein or subclavian vein was selected as the conventional venous approach. Through the venous approach, a super-smooth guide wire (0.035 inch) passed across the tricuspid valve annulus and been sent to the position of pulmonary artery. Under the right anterior oblique (RAO) 30° fluoroscopy view, the “C315-S4” delivery sheath was placed in and maintained it’s tip closing to the interventricular septum. Under the left anterior oblique (LAO) 40° fluoroscopy view, the delivery sheath was fine-tuned in order to maintain being perpendicular to the interventricular septum. The “3830” electrode was placed in through the delivery sheath and penetrated into the interventricular septum (the region of left branch bundle). Meanwhile, the pacing test was performed. When the left bundle branch has been captured successfully, an angiography was performed. The depth of the electrode penetrating into the interventricular septum was measured under LAO 40° fluoroscopy view (Fig. 1A). After the electrode was stabilized, routine pacing test was performed under unipolar and bipolar pacing output respectively (pacing parameters including: capture threshold, impedance and R-wave amplitude were measured). After the satisfactory pacing parameters were confirmed, the delivery sheath was withdrawn, and the ventricular electrode was reserved some lengths in order to maintain a suitable curvature in right atrium or inferior vena cava. Eventually, the electrode and the pulse generator were connected, then the pacemaker pocket was closed.

Criteria for successful practice of LBBaP [8]: 1. The electrode was placed in the region of left bundle branch and the potential of left bundle branch was recorded (Fig. 1B); 2. The paced electrocardiogram (ECG) showed a pattern of right bundle branch block (Fig. 1B); 3. The peak activation time of left ventricle (Sti-LVAT): The interval which be calculated from the stimulus signal to the peak of “R” wave on lead V5 or V6. Under the condition of unipolar pacing (from low voltage output to high voltage output), the Sti-LVAT was shortened abruptly or remained the shortest and constant (Fig. 1C).

3.Observation data

During operation, the procedure time, fluoroscopic exposure time, fluoroscopic exposure dose, and the pacing parameters (capture threshold, impedance, R-wave amplitude and current of injury) were recorded. Additionally, the surgery related complications such as myocardial perforation, electrode malfunction, electrode dislodgement, pocket hematoma and venous thrombosis during follow-up were recorded.

Examination of echocardiography (echo): The left ventricular end-diastolic dimension (LVEDD) was measured by two-dimensional echocardiography. The left ventricular ejection fraction (LVEF) was calculated from the apical two-chamber and four-chamber views using the Simpson method. The left ventricular end-systolic volume (LVESV) index was calculated from LVESV and corrected by the body surface area. The end-systolic thickness of interventricular septum was measured under the view of left ventricular long axis.

Assessment of the cardiac synchrony: Using two-dimensional ultrasound speckle tracking technology (STE) to obtain the strain-time curves of left ventricular 18-segments from the apical four-chamber, three-chamber, and two-chamber views respectively. The intraventricular synchrony parameters were calculated as following: the global peak longitudinal strain of left ventricle (GLS), the standard deviation of time to peak strain (Ts-SD) and the maximal delay time to peak strain among all segments (MDT). The assessment process of intraventricular synchrony was shown in Fig. 2. The Ts-SD 40ms or MDT 130ms was considered as intraventricular dyssynchrony [9]. The mechanical delay time between left ventricle and right ventricle (interventricular mechanical delay time, IVMD) was calculated by the method of tissue doppler imaging (TDI) technology. The IVMD 40ms was considered as interventricular dyssynchrony [10].

4.Follow-up

Three months, six months, one year and subsequent follow-ups were performed once a year. At each time of follow-up, the following examinations were completed: ECG, Holter, pacemaker programming, chest Xray film, and echocardiography. The capture threshold of electrode was measured under the condition of bipolar pacing with the width of output pulse as 0.4ms.

5.Statistical methods

The SPSS 19.0 software was used for statistical analysis. Continuous variables with normal distributed are expressed as mean ± standard deviation(x ± s), and continuous variables with abnormal distributed are expressed as median (interquartile rage, IQR). The categorical data are expressed as the number of cases (percentage %). The comparison of continuous variables between the patients of two groups is adopted Student's t test. The comparison between preoperative and postoperative continuous variables use the method of paired sample t test. The result of bilateral P< 0.05 is considered as statistically significant.

Result

1.General

The operation of LBBaP was attempted for thirty-one children (seventeen males and fourteen females) with a mean age of 3.2 ± 2.1 (range 0.7 ~ 7.0) years old, and weight of 14.1 ± 5.7 (range 7.0 ~ 28.0) kg. All patients were diagnosed as complete atrioventricular block. The median duration of bradycardia history in these patients was 1.5 (IQR 0.08–3.7) years. In these patients, the results of Holter before the pacemaker implantation showed that: the average of total heartbeat was 6.6 ± 0.8 thousand beats per 24 hours, and the average of heart rate was 47 ± 5 beats per minutes (bpm). Congential heart disease was presented in 35.5% of patients (11/31 cases), in which of eight patients underwent cardiac surgery previously (including: one case of atrial septal defect, five cases of ventricular septal defect, and two cases of complete endocardial cushion defect). Before pacemaker implantation, abnormal cardiac structure was still present in three patients (including: two cases of atrial septal defect and one case of patent ductus arteriosus). These three patients underwent transcatheter occlusion before pacemaker implantation. Twenty-seven patients (87.1%) were implanted with pacemaker for the first time, and four patients (12.9%) were received reoperation due to the previous epicardial pacemaker or electrode malfunction at this time. Before pacemaker implantation, left ventricular enlargement was seen in twenty-four patients (24/31, 77.4%) (echo-LVEDD Z score > + 2), and normal LVEDD (-2 LVEDD Z score +2) was seen in other patients (7/31, 22.6%). Before pacemaker implantation, normal echo-LVEF was seen in all patients with the mean value of 68.1 ± 3.9%.

2.Pacemaker implantation

One patient was implanted with dual-chamber pacemaker (DDD) and thirty patients were implanted with single-chamber pacemaker (VVIR). The operation of LBBaP was succeeded in twenty-two patients with the success rate of 70.9% (22/31 cases). The operation of LBBaP had failed in nine patients, for these patients the right ventricular septal pacing (RVSP) was performed eventually. The comparison of baseline data and intraoperative parameters between the patients of LBBaP group and the patients of RVSP group was seen in Table 1. At baseline, there was no significant difference in terms of patients' age, body weight and echo-indicators between two groups (P 0.05). In patients of LBBaP group, the average age was 3.3 ± 2.1 (range 0.8 ~ 7) years old and the average body weight was 14.7 ± 6.0 (range 7.0 ~ 28.0) kg.

Table 1
The comparison of baseline data and intraoperative parameters between the patients of LBBaP group and the patients of RVSP group

	LBBaP group(N = 22)	**RVSP group (N = 9)**	***P*-value**
Baseline Data			
Age(years old)	3.3 ± 2.1	2.9 ± 2.0	0.578
Body weight(kg)	14.7 ± 6.0	12.6 ± 5.0	0.359
LVEDD Z score	3.0 ± 1.4	2.8 ± 1.6	0.672
LVEF (%)	68.5 ± 3.8	67.2 ± 3.4	0.367
LVESV index (ml/m^2)	19.3 ± 4.6	20.7 ± 7.3	0.608
IVS (mm)	5.1 ± 0.8	5.0 ± 0.9	0.821
Intraoperatively parameters			
Capture threshold of ventricular electrode (V)	0.5 ± 0.1	0.6 ± 0.1	0.418
R-wave amplitude of ventricular electrode (mV)	14.0 ± 3.8*	9.6 ± 4.7	0.015
Impedance of ventricular electrode (Ω)	728.1 ± 138.6	672.0 ± 107.0	0.286
Sti-LVAT(ms)	51.2 ± 7.8*	66.7 ± 8.0	0.000
QRS duration on ECG (ms)	100.9 ± 9.1*	114.2 ± 11.9	0.002

*The comparison between two groups when P 0.05 was presented. LVEDD = left ventricular end-diastolic dimension. LVEF = left ventricular ejection fraction. LVESV = left ventricular end-systolic volume. IVS = thickness of interventricular septum. Sti-LVAT = the peak activation time of left ventricle. ECG = electrocardiogram

In LBBaP group, the potential of left bundle branch was successfully recorded in 63.6% of patients (14/22 cases) during operation. In patients who received the operation of LBBaP successfully, the average of procedure time (calculated from the time when the guide wire passed across the tricuspid valve annulus to the time that the ventricular electrode was fixed) was 21.8 ± 13.3 minutes (min). The average of instant current of injury was 10.7 ± 3.9 mV. The average of fluoroscopic exposure dose was 3.6 ± 1.9 mGy, the fluoroscopic exposure time was 7.2 ± 3.2 min, the cumulative product of area and fluoroscopic exposure dose (DAP) was 564.7 ± 319.2 mGycm^2. In the patients of LBBaP group, the average thickness of interventricular septum (measured by echocardiography preoperatively) was 5.1 ± 0.8 mm and the average depth which the ventricular electrode penetrating into the interventricular septum (measured by angiography during operation) was 7.7 ± 1.9 mm.

In the nine patients who had failed LBBaP, it was difficult to screw the ventricular electrode into the interventricular septum. Additionally, the electrode was unable to be placed in the region of left bundle branch. In three of these patients were diagnosed as congenital heart disease and they underwent cardiac surgery previously (two patient received the surgery of endocardial cushion defect correction, and one patient received the surgery of ventricular defect repairation).

The postoperative QRS duration in patients of LBBaP group was significantly narrower than that of RVSP group: 100.9 ± 9.1 vs. 114.2 ± 11.9 ms ($P = 0.002$). The comparison of postoperative echocardiographic image and ECG between one patient with LBBaP and another patient with RVSP was seen in Fig. 3.

In all over patients, no surgery related complications such as myocardial perforation, electrode malfunction, electrode dislodgement, pocket hematoma and venous thrombosis had occurred.

3.Follow-up

3.1 Complications and the pacing parameters

For all patients, the median time of follow-up was 12 (IQR 6–15) months. The pacing mode of VVIR was adopted for the patients with single-chamber pacemaker (30 cases) and the pacing mode of DDD was adopted for the patient with dual-chamber pacemaker (1 case). The average percentage of ventricular pacing was 96.0 ± 2.5%. The lower limit of pacing frequency was set as 70 (IQR 60–70) bpm, and the upper limit of pacing frequency was set as 140 (IQR 130–140) bpm. During follow-up, no complications (e.g., electrode perforation, electrode malfunction, pocket infection) had occurred.

In the patients of LBBaP group, the capture threshold and the R-wave amplitude of ventricular electrode maintained well during follow-up. The impedance had decreased obviously than baseline. The comparison of capture threshold of ventricular electrode between baseline and last time of visit was as follows: 0.58 ± 0.13 vs. 0.70 ± 0.25 V ($P = 0.054$). The comparison of R-wave amplitude of ventricular electrode between baseline and last time of visit was as follows: 14.0 ± 3.8 vs. 16.5 ± 4.5 mV ($P = 0.072$). The comparison of impedance of ventricular electrode between baseline and last time of visit was as follows: 728.1 ± 138.6 vs. 552.5 ± 74.0 Ω ($P = 0.000$).

During follow-up, the average capture threshold of ventricular electrode in patients of LBBaP group was obviously lower than that of RVSP group. Additionally, the R-wave amplitude in patients of LBBaP group was better than that of RVSP group. At last time of follow-up, the comparison of capture threshold between LBBaP group and RVSP group: 0.70 ± 0.25 vs 1.39 ± 0.94 V ($P = 0.011$). The change trend of pacing parameters in patients of two groups during follow-up was shown in Fig. 4.

3.2 Cardiac function

All the patients of LBBaP group had maintain a well cardiac function during follow-up, the echo-LVEDD Z score and LVESV index were significantly decreased than that of baseline. Additionally, the ehco-LVEF in patients of LBBaP group maintained normal during follow-up. The comparison of echo-indicators between baseline and last time of visit was shown in Fig. 5.

At last time of follow-up, the comparison of echo-LVEDD Z score in patients of LBBaP group and the patients of RVSP group was as follows: 0.5 ± 1.2 vs. 1.1 ± 0.7 (P = 0.220). The average of echo-LVEF in patients of LBBaP group was better than that of RVSP group was as follows: 66.1 ± 3.3 vs. 63.1 ± 2.2% (P = 0.025). The change tendency of echo-indicators in patients of LBBaP group and RVSP group during follow-up was shown in Fig. 6.

3.3 Assessment of cardiac synchrony

At baseline, there was no significant difference in terms of cardiac synchrony parameters in patients of LBBaP group and the patients of RVSP group: GLS (-24.3 ± 1.8 vs. -22.7 ± 3.0%), Ts-SD (41.8 ± 9.5 vs. 49.3 ± 10.4 ms), MDT (147.6 ± 49.1 vs. 169.2 ± 51.6 ms), and IVMD (40.8 ± 33.1 vs. 20.0 ± 14.1 ms), all of P value 0.05.

Postoperatively, the average of Ts-SD, MDT and IVMD in patients of LBBaP group were all better than that of RVSP group (Fig. 7).

Discussion

In 2017, Huang et al. firstly performed the procedure of left bundle branch pacing for an adult with dilated cardiomyopathy [11]. Subsequent studies had confirmed the safety and effectiveness of the LBBaP [4, 5]. The success rate of the LBBaP was 80.5 ~ 93% which was reported in adult studies [12, 13]. In this study, the success rate of the LBBaP was 70.9% and without surgical complications. Additionally, the pacing parameters in patients of LBBaP group maintained well during follow-up. The success rate of the LBBaP in children is slightly lower than that in adults. The possible reasons are as follows: 1. Currently, the selectable implantation devices are designed for adults but are not completely suitable for children. 2. Children have the smaller body size than adults, additionally there is individual difference in different ages of children. 3. Some children have congenital heart disease concomitantly. The abnormal cardiac structure would increase the difficulty of electrode implantation.

Few data are available on the application of LBBaP performing in children, some studies had reported a series of cases in adolescents (≥ 9 years old) [14]. But there is no data referred to young children or infants. In this study, the average age of children who received LBBaP successfully was 3.3 ± 2.1 years old and the average weight was 14.7 ± 6.0 kg (the minimum age of 10 months, and the lowest weight of 7.0 kg). The results suggested that the operation of LBBaP is also suitable for young children. Nevertheless, the operation of LBBaP for young children still face some technical challenges. The size and the curvature of “C315-His” delivery sheath (length of 43 cm) are not suitable for children. Selecting the “C315-S4” delivery sheath (length of 30 cm) and reshaping the delivery sheath beforehand will help to improve the success rate of the surgery. In this study, the average thickness of interventricular septum in patients of LBBaP group was 5.1 ± 0.8 mm, which was thinner than that in other similar reports (7.5 ~ 9.5 mm) [15]. It is important to judge the depth which the electrode penetrating into the interventricular septum. In this study, we estimate the penetration depth and the position of electrode by the method of angiography. Meanwhile, the observation of the changes of ECG is essentially. Maintaining a suitable position of electrode could not only make the left bundle branch has been captured successfully, but also achieve a satisfactory capture threshold. In this study, the average depth which the electrode penetrating into the interventricular septum was 7.7 ± 1.9 mm. There is some contradiction between the echo-thickness of interventricular septum and the depth of the electrode penetrating into the interventricular. On the one hand, there is difference between two methods of measurement (the former one is measured by echocardiography which be performed under the long axis view of left ventricle, the latter one is measured by fluoroscopy which be performed at the left anterior oblique 40° view). On the other hand, actually it is an oblique route but not a vertical route which the electrode penetrating into the interventricular septum. In this study, the average of Sti-LVAT in patients of LBBaP group was 51.2 ± 7.8 ms, which was significantly shorter than that in adult studies (68–79 ms) [5, 12, 16]. The size of cardiac chamber in children are different from adults. Hence, it is not suitable to extrapolate the standard method used in adults to children.

The operation of LBBaP performing in pediatric populations has its particularity. For the children with congenital heart disease and underwent cardiac surgery previously, the difficulty of electrode implantation would increase due to the intraventricular patch or surgical scar [14, 15]. In this study, total of eight patients with congenital heart diseases underwent cardiac surgery before the pacemaker implantation. In which three of these patients, the electrode was difficultly placed in the region of left bundle branch. Therefore, a fully understood of surgical history is crucial. If the procedure of LBBaP had failed, searching another pacing site should be considered. The recording of left bundle branch potential has a guidance for judging the success of LBBaP. The potential of left bundle branch were recorded in 55% of children that reported by Dai [15], and the recording rate was 63 ~ 66% in adult studies [5, 12]. In this study, the potential of left bundle branch was recorded successfully in 63.6% of patients during operation. In the patients without recording the potential of left bundle branch, observing the changes of paced ECG under the condition of different voltage output would also help to determine whether the left bundle branch has been captured successfully.

In some literatures related to the His bundle pacing performed in adult patients, the capture threshold of ventricular electrode had increased during follow-up [17]. The technology of LBBaP overcome the shortcoming of His bundle pacing, and the pacing parameters maintained well during LBBaP [5]. In this study, the average capture threshold of ventricular electrode in patients of LBBaP group was significantly lower than that of RVSP group during follow-up. The average R-wave amplitude of ventricular electrode in patients of LBBaP group was better than that of RVSP group. Maintaining a well postoperative pacing parameters could prolong the service life of the pacemaker, on the other hand it could avoid the surgical complications related to device replacement and reduce the economic burden. That is important for children who are highly dependent on pacing support. This study proved that the LBBaP has an advantage on maintaining better postoperative pacing parameters over RVSP. Studies showed that compared with RVSP, the LBBaP could achieve a narrower QRS duration [18]. In this study, the average paced QRS duration in patients of LBBaP group was significantly narrower than that of RVSP group. All the patients of LBBaP group had maintained a good cardiac function during follow-up, the echo-LVEDD Z score and echo-LVESV index were significantly reduced postoperatively. During follow-up, the ehco-LVEDD Z score and echo-LVEF in patients of LBBaP group were all better than that of RVSP group. Additionally, the assessment results of cardiac synchrony showed that the intraventricular synchrony parameters and the interventricular synchrony parameters in patients of LBBaP group were obviously better than that of RVSP group. A well postoperative cardiac synchrony is beneficial for children to maintain the long-term effect of pacing therapy, and avoid the cardiac dysfunction. In conclusion, the operation of LBBaP has more advantage over RVSP in terms of postoperative pacing parameters, QRS duration and cardiac synchrony.

Conclusion

The operation of LBBaP is safe and effective for young children. Satisfactory pacing parameters, narrow QRS duration and better cardiac synchrony parameters could be obtained, which is conducive to maintain a well cardiac function and therapeutic effect.

Declarations

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Data Transparency All data and materials as well as software application or custom code support our published claims and comply with field standards.

Declarations

Conflict of Interest Authors in this study declare that they have no conflict of interest.

Ethical Approval This is an observational study. All procedures in this study involving human participants were performed in accordance with the ethical standards of the institution and the Helsinki Declaration of 1964. This study was approved by the ethics committee of our hospital (Ethics Document Batch Number: 202003).

Inform Consent Every patient was given an informed consent form and an anesthesia consent form. Consent forms had been signed by patient’s guardian before pacemaker implantation.

Consent for Publication Not applicable.

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Figures

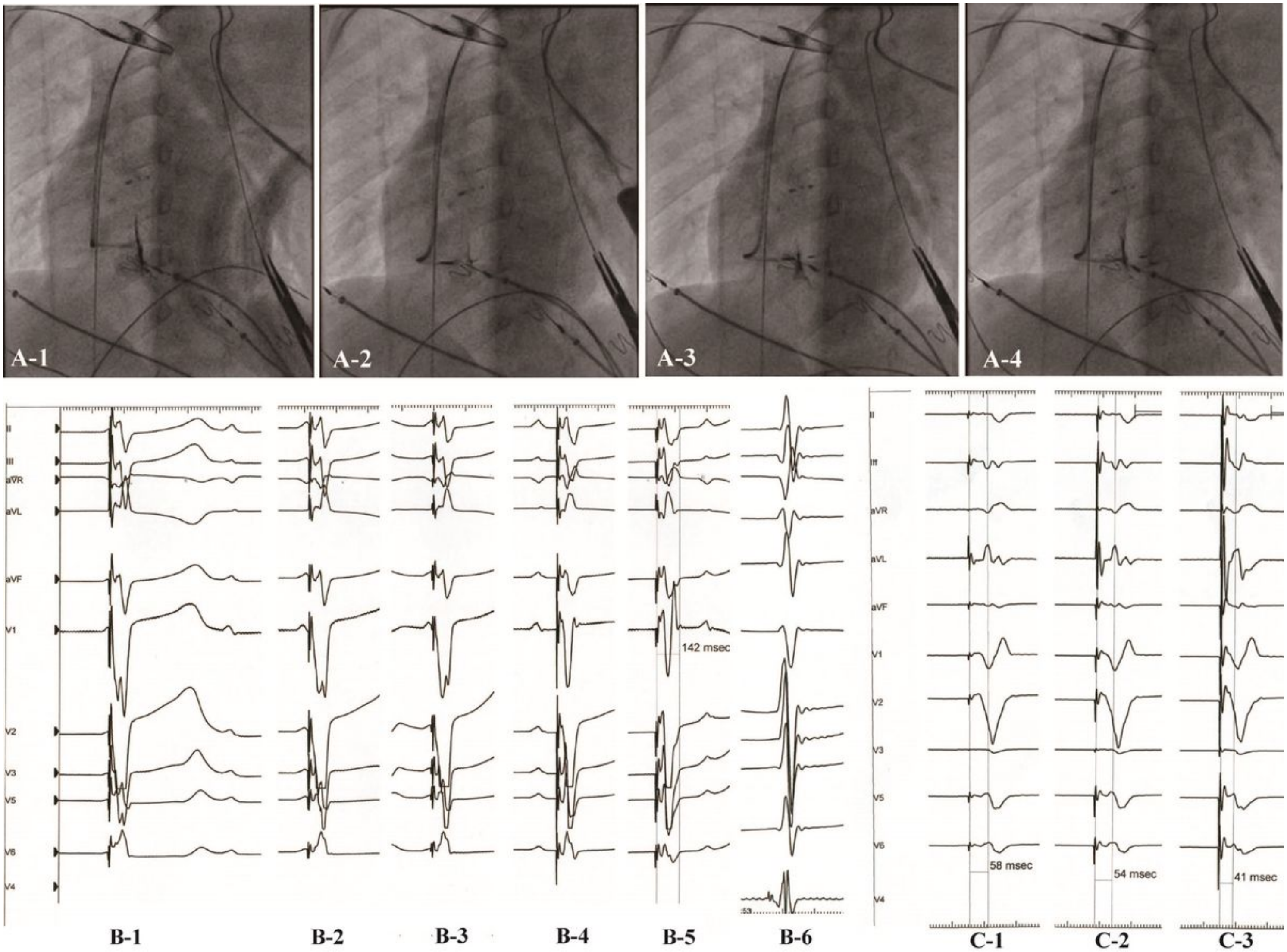

Figure 1

The process of the electrode implantation under the guidance of fluoroscopy intraoperatively. FigureA-1 to A-4: The “C315-S4” delivery sheath was placed into right ventricle and reaching the region of interventricular septum. The angiography was performed under the left forward oblique 40° fluoroscopy view in order to observe the position of the electrode. The electrode was screwed clockwise that penetrated into the interventricular septum. Figure B-1 to B-5: Firstly, the QRS complex on lead V1 of electrocardiogram (ECG) presented the pattern of “QS”. With the change of the electrode’s position, a low amplitude of “r” wave appeared at the nadir of QRS complex of lead V1. With the amplitude of the “r” wave elevating, the QRS complex on lead V1 turned into the pattern of “M”. Figure B-6: The potential of left bundle branch was recorded intraoperatively (see the bottom one of ECG channels). Figure C-1 to C-3: The The peak activation time of left ventricle (Sti-LVAT) was measured under different voltage outputs (from 1 V to 10 V). In this patient, the Sti-LVAT had abruptly shorten and maintained constant (from 58 to 41 ms).

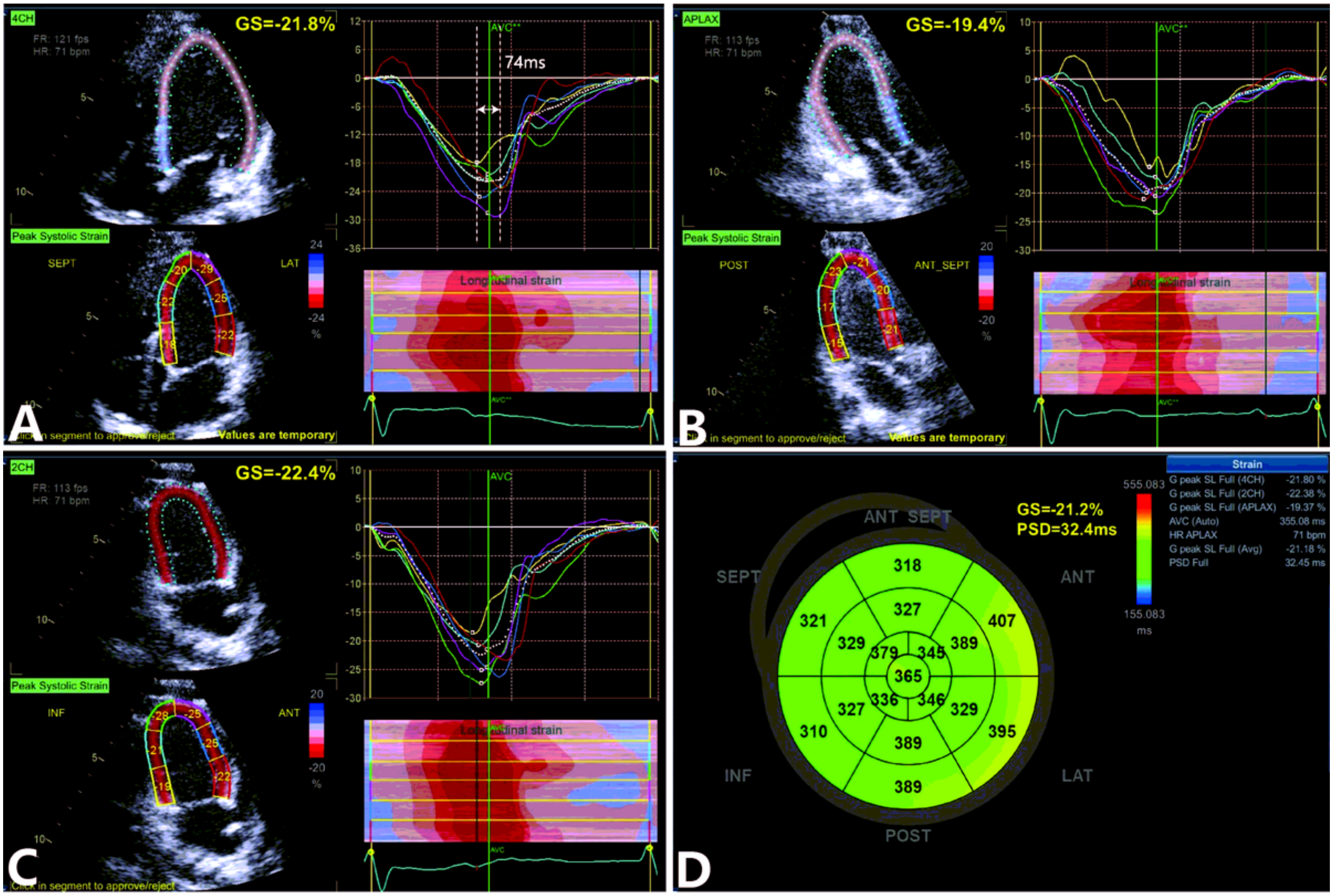

Figure 2

Assessment process of intraventricular synchrony. Using two-dimensional ultrasound speckle tracking technology to obtain strain-time curves of left ventricular 18-segments from the apical four-chamber view (Figure A), three-chamber view (Figure B), and two-chamber view (Figure C) respectively. In figure A, the maximal delay time (MDT) to peak strain among all segments was measured. The yellow color of curve represented the base-septal segment (the earliest one that reached to peak stain), and the red color of curve represented the base-lateral segment (the latest one that reached to peak strain). In figure D, the “bull’s eye” image which representing the 18-segments of left ventricle was built. The global peak longitudinal strain (GLS) and the standard deviation of time to peak longitudinal strain (Ts-SD) were calculated respectively. In this patient, the GLS was -21.2% and the Ts-SD was 32.4 ms.

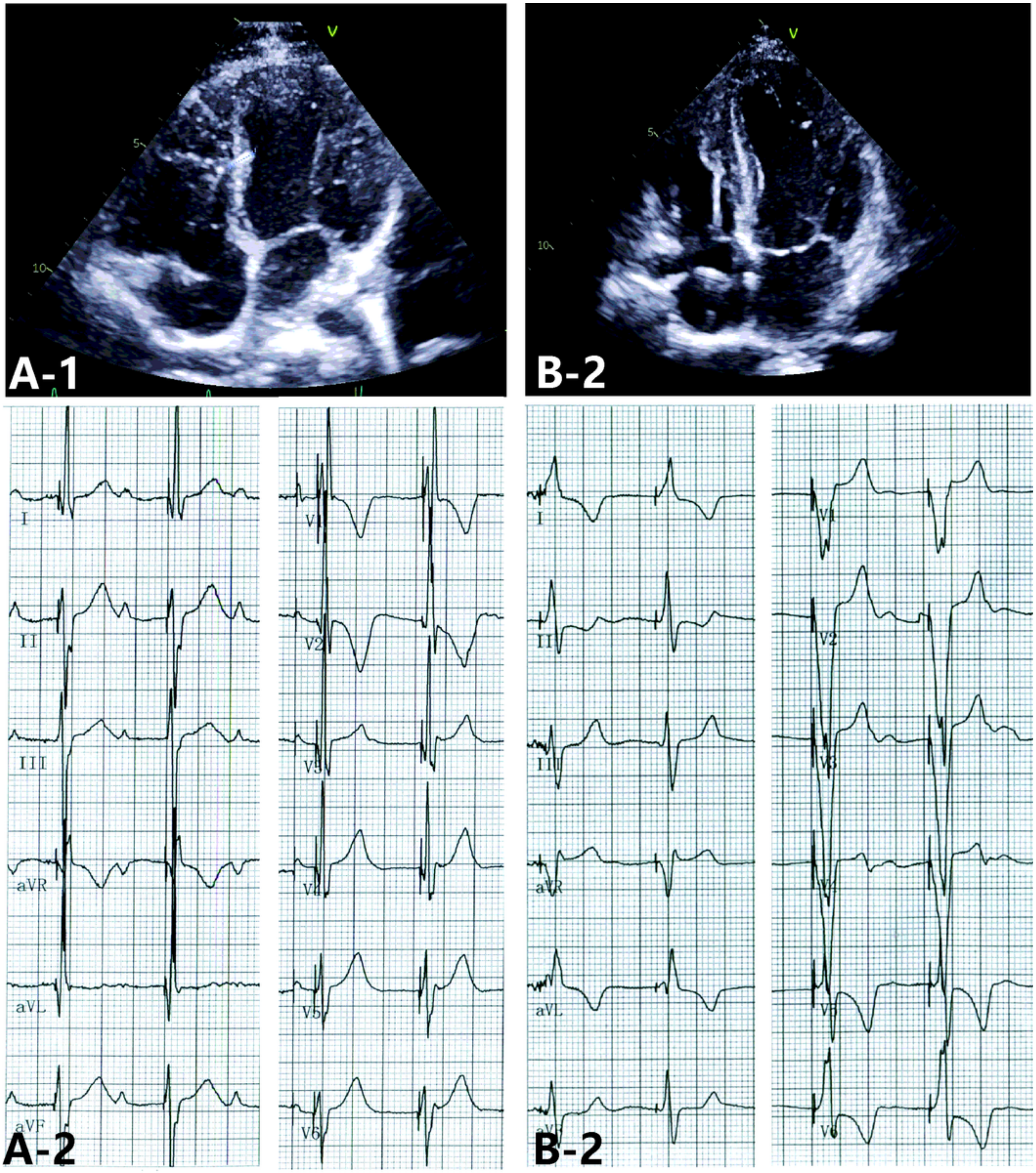

Figure 3

The comparison of postoperative echocardiographic image and electrocardiogram (ECG) between one patient with LBBaP and another patient with RVSP. Figure A-1 and A-2: The postoperative echocardiographic image and ECG in one patient with LBBaP. As shown in Figure A-1, the tip of ventricular electrode was penetrating into the interventricular septum. The QRS duration was 92 ms, and the ECG was presented as the pattern of right bundle branch block. Figure B-1 and B-2: The postoperative

ECG in one patient with RVSP. The tip of ventricular electrode was fixed at the surface of interventricular septum. The QRS duration was 140 ms, and the ECG was presented as the pattern of left bundle branch block. The QRS duration in this patient was wider than that of the former one.

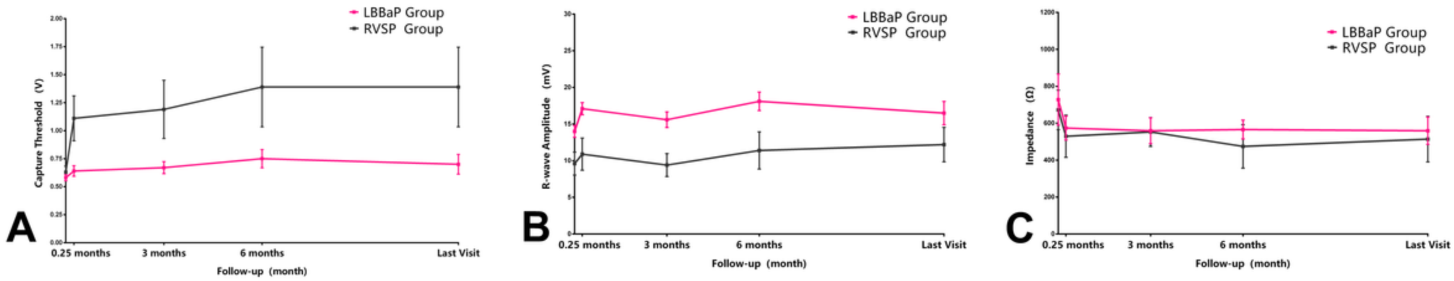

Figure 4

The change trend of pacing parameters of ventricular electrode in patients of LBBaP group and the patients of RVSP group during follow-up. A: The change tendency of capture threshold. B: The change tendency of R-wave amplitude. C: The change tendency of impedance.

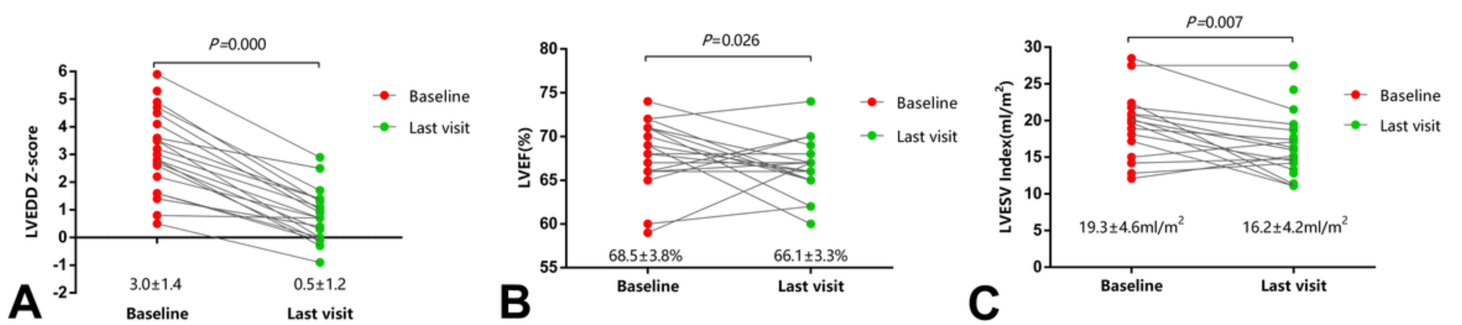

Figure 5

The comparison of echocardiographic indicators in patients of LBBaP group between baseline and the last time of visit. A: The comparison of left ventricular end-diastolic dimension (LVEDD) Z score. B: The comparison of left ventricular ejection fraction (LVEF). C: The comparison of left ventricular end-systolic volume (LVESV) index.

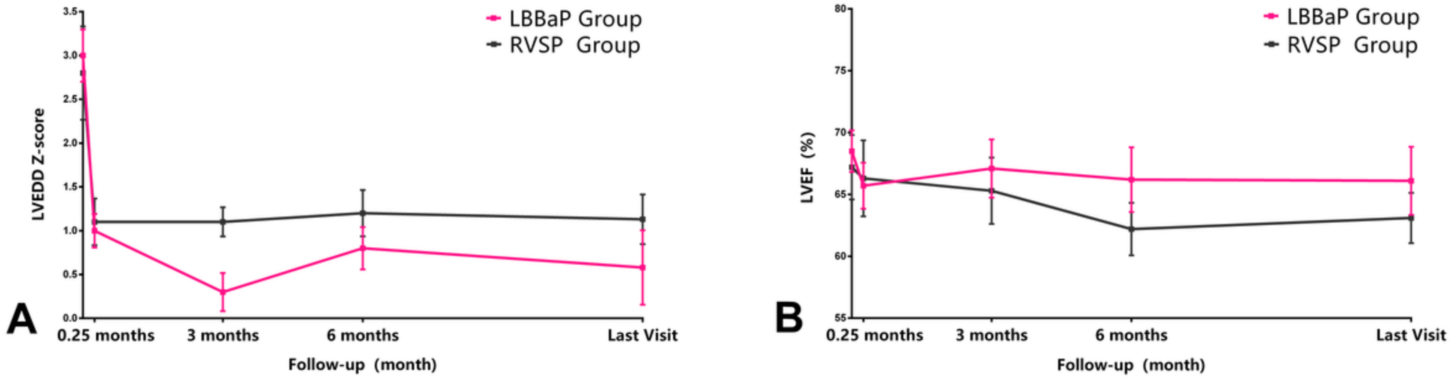

Figure 6

The change trend of echocardiographic indicators in patients of LBBaP group and the patients of RVSP group during follow-up. A: The change tendency of left ventricular end-diastolic dimension (LVEDD) Z score. B: The change tendency of left ventricular ejection fraction (LVEF).

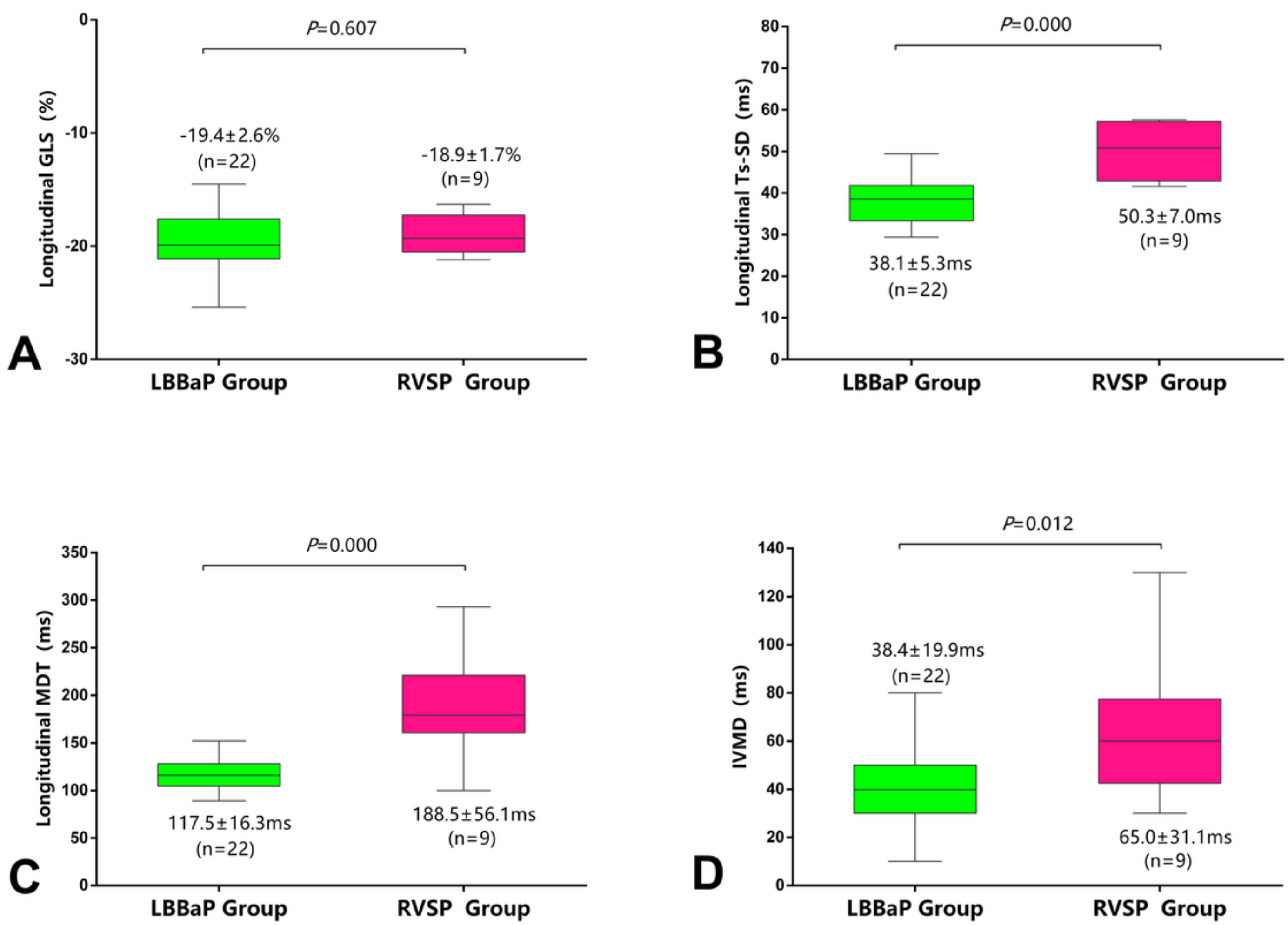

Figure 7

The comparison of postoperative cardiac synchrony parameters between the patients of LBBaP group and the patients of RVSP group. A: The comparison of global peak longitudinal strain (GLS) in patients of two groups. B: The comparison of the standard deviation of time to peak longitudinal strain (Ts-SD) in patients of two groups. C: The comparison of the maximal delay time to peak strain among all segments (MDT) in patients of two groups. D: The comparison of interventricular mechanical delay time (IVMD) in patients of two groups.