

Acute effect of multipoint pacing and fused AV delay in patients receiving cardiac resynchronization therapy

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Abstract

Background: Cardiac resynchronization therapy (CRT) is an established treatment for patients with heart failure with dyssynchrony. However, one-third of patients do not respond positively to it. Recently, multipoint pacing (MPP), which involves pacing from two sites on the left ventricle, has been found to improve symptoms and hemodynamics compared to conventional CRT. An automatic fused atrioventricular (AV) delay that performs fused pacing for intrinsic conduction has also been introduced. However, the combined effect of MPP and fused AV delay on acute hemodynamics is unknown. **Objective:** To evaluate the acute hemodynamic effects of MPP and fused AV delay in patients undergoing CRT.

Methods: A pressure wire was delivered to the left ventricle, and dp/dt was compared with single atrial stimulation pacing in 52 patients with various pacing configurations.

Results: Delta dp/dt was greater in MPP than in conventional CRT ($10.5 \pm 1.0\%$ vs. $8.2 \pm 1.0\%$, $p < 0.001$) and in fused AV delay than in short AV delay ($10.4 \pm 0.8\%$ vs. $8.3 \pm 1.1\%$, $p < 0.001$). Hemodynamic parameters significantly most improved with the combination of MPP and fused AV delay. Delta dp/dt was greater in LV pacing than in biventricular (BiV) pacing with MPP and fused AV delay; however, the delta QRS duration was shorter in LV pacing than in BiV pacing. Delta dp/dt and delta QRS duration were negatively correlated. The super-responder rate was 66%.

Conclusion: Combining MPP and fused AV delay has an additional effect. Shortening the QRS duration can increase the dp/dt, but the estimated line differs between LV and BiV pacing.

KEYWORDS

cardiac resynchronization therapy, dp/dt, fused AV delay, LV pacing, multipoint pacing

1 | INTRODUCTION

Over the last decade, cardiac resynchronization therapy (CRT) has evolved considerably, becoming an established treatment option for patients with symptomatic heart failure (HF) with prolonged QRS duration and reduced ejection fraction.^{1–6} However, the clinical response to CRT remains highly variable, and many patients fail to respond positively.^{5,6} Therefore, the current clinical focus in CRT is to maximize the benefit of this therapy. Many reasons have been suggested for inadequate response to CRT therapy, including persistent left ventricular (LV) dyssynchrony after CRT, phrenic nerve stimulation, lead dislodgement, or suboptimal programming of devices, including AV or VV delay optimization.⁷ Recent studies suggest that multipoint pacing (MPP) via an LV quadripolar pacing lead may be an alternative approach to improve CRT response by simultaneously increasing myocardial volume. Acute and chronic benefits have been demonstrated with MPP,^{8–14} including electrical synchronization,¹⁰ mechanical synchronization,¹² and hemodynamic improvement.⁸

Further improvement in the hemodynamic response in CRT is achievable by optimizing AV delay.¹⁵ However, manual programming is time-consuming, often needs echocardiography and exercise testing, and is therefore neglected in actual clinical practice. A novel technology utilizing automatic timed ventricular stimulation so that fusion of intrinsic activation, which could reduce QRS duration, heart failure hospitalization or death, and development of chronic atrial fibrillation has been recently developed.^{16–20}

However, reports on combining MPP with fused AV delay are limited.^{21,22} This study aimed to evaluate the acute hemodynamic changes in MPP with fused AV delay in patients with HF receiving CRT.

2 | METHODS

2.1 | Study population

In our institute, LV dp/dt measurement in various pacing configurations has been done before or after CRT implantation to confirm the effect of CRT since 2002 in patients who provided written informed consent to be examined for LV dp/dt and QRS duration using various pacing configurations. From 2018 to 2023, 66 patients with MPP capabilities were analyzed retrospectively. The study protocol was approved by the Institutional Review Board and Medical Ethics Committee of Okayama University Hospital according to the Helsinki declaration. Right ventricular leads were implanted in the mid-septum, atrial leads in the right atrial appendage, and LV leads in the anterolateral, lateral, or posterolateral coronary veins according to our standard implantation procedure in all patients.

Three patients were excluded because of atrial fibrillation, five did not have stable antegrade AV conduction, and we were unable to capture at least one electrode of the LV lead for six patients.

The remaining 52 patients who received CRT [(13 used Abbott, Chicago, IL), 30 used Medtronic (Mounds View, MN), four used Boston Scientific (Marlborough, M), and five used Biotronik (Berlin, Germany)] with sinus rhythm, maintained antegrade AV conduction, and were capable of pacing in all four electrodes of the LV quadripolar lead were included in this retrospective study.

2.2 | Delta dp/dt and delta QRS duration

After CRT with a pacemaker or defibrillator, 4F sheaths were inserted into the radial or femoral artery, followed by the injection of 3 mL heparin. A 0.014 pressure sensor guidewire (Certus Pressure Wire, Abbott, Chicago, IL) through 4F Pigtail or multipurpose catheters was inserted into the left ventricular cavity (Graphical abstract A). All patients were examined in the supine position in a silent environment to reduce the impact of external stimuli on sympathetic activation. The pacing protocol was as follows: All pacing outputs were set to twice the pacing threshold. Single atrial stimulation (AAI) pacing was performed at a stable rate of 5–10 beats per min above the intrinsic heart rate, and dp/dt was measured. Subsequently, CRT pacing was continued for 2 min at the same pacing rate as in AAI mode; dp/dt was measured, and the procedure was repeated to examine all pacing configurations. The delta dp/dt was calculated as follows: (dp/dt in CRT–dp/dt in AAI)/dp/dt in AAI. Additionally, the delta QRS duration was calculated as follows: (QRS duration in CRT–QRS duration in AAI)/QRS duration in AAI. The order of each pacing configuration was randomly selected to avoid the effect of continuous CRT pacing.

In 52 patients, examined CRT pacing configurations were LV 1, 2, 3, 4 as conventional CRT (c-CRT), and LV 1–2, 1–3, 1–4, 2–3, 2–4, 3–4 as MPP (2–3 was not available in 30 patients with Medtronic device) in both short AV delay of 120 ms based on the previous study²³ and fused AV delay. In 24 patients with an intrinsic AV delay of <270 ms, LV pacing was examined during MPP and fused AV delay. The most increased delta dp/dt was selected as the delta dp/dt among LV 1, 2, 3, and 4 for c-CRT for each AV delay. Similarly, the most increased delta dp/dt was selected as the delta dp/dt among LV 1–2, 1–3, 1–4, 2–3, 2–4, and 3–4 for the MPP in each AV delay.

We employed two fused AV-delay algorithms based on the manufacturer's instructions for the devices. First fused AV delay was –50 ms from the intrinsic AV delay (Abbott, Biotronik, Boston and Medtronic: At the time of writing this, Boston Scientific and Biotronik did not have the auto fusion function for AV delay), which was used for almost the study, but not LV only pacing.

The calculation of the second fused AV delay was as follows: if the intrinsic AV delay was >270 ms, the shortest AV delay was selected among P wave duration +20 ms, –50 ms from intrinsic AV delay, or $0.125 \times (3 \times \text{intrinsic AV delay} + 550 \text{ ms})$; if the intrinsic AV delay was ≤270 ms, the shortest AV delay was selected among $0.7 \times \text{intrinsic AV delay}$, –40 ms from intrinsic AV delay, or $0.5 \times (\text{intrinsic AV delay} + 90 \text{ ms})$, which was used at the time of LV only pacing. VV delay was set to 0 in all cases.

2.3 | 6-month follow-up

The 41 patients with automatic fused AV delay were followed up for at least 6 months and underwent echocardiographic examination. The pacing configuration was selected by the results of delta dp/dt in the acute study, except for high pacing threshold or phrenic nerve stimulation. A responder was defined as a patient with a decrease in the left ventricular end-systolic volume (LVESV) of >15%, and a super-responder was defined as a patient with a decrease in LVESV of >30%.

2.4 | Statistical analysis

Continuous data were summarized as means and standard deviations (patient characteristics) or standard error (delta dp/dt or delta QRS duration) and compared among groups using the Kruskal-Wallis test. Categorical data are summarized as frequencies and percentages and compared using Pearson's Chi-square test. We evaluated the differences between c-CRT and MPP, short AV delay and fused AV delay, BiV pacing and LV pacing, and calculated *p*-values using a paired *t*-test. The value with the largest dp/dt ratio was used for each category: c-CRT with short AV delay, MPP with short AV delay, c-CRT with fused AV delay, MPP with fused AV delay, MPP with LV pacing, and fused AV delay. A one-way analysis of variance was used to compare the four groups. Among four categories (c-CRT with short AV delay, MPP with short AV delay, c-CRT with fused AV delay, MPP with fused AV delay), MPP with fused AV delay was compared with other three categories by using Bonferroni's modification method. In this analysis, statistical significance was set at *p* < 0.016 (0.05/3).

All tests were two-sided, and statistical significance was set at *p* < 0.05. All statistical analyses were performed using JMP version 13.2 (JMP STATISTICAL DISCOVERY Inc., Cary, NC, USA).

3 | RESULTS

3.1 | Patient characteristics

In total, 52 patients in sinus rhythm and maintained intrinsic AV conduction were evaluated. Patient characteristics are presented in Table 1. The mean age was 67.7 ± 9.9 years, 35 (68.6%) were male, preoperative LV ejection fraction was $29.2 \pm 7.6\%$, and QRS duration was 148.6 ± 21.0 ms. Precisely 43 (84.3%) patients suffered from non-ischemic cardiomyopathy, and 31 (60.8%) had complete left bundle branch block. All patients successfully underwent implantation of a quadripolar lead in the lateral or anterolateral/inferolateral vein with no complications, and an acute hemodynamic change evaluation was successfully performed without complications. Electrical parameters and delta dp/dt in each pacing configuration are given in Table 2. The delta dp/dt was significantly higher in electrode 1 or 3 than those of electrode 4. In MPP, the wider the distance between electrodes (1–4), the higher

TABLE 1 Patient characteristics.

	Total
N	52
Male, n (%)	35 (67.3)
Age, years	67.9 ± 9.9
NYHA class, n (%)	
I	0 (0)
II	25 (48.1)
III	22 (42.3)
IV	5 (9.6)
Ejection fraction, %	29.0 ± 7.6
Log BNP	2.5 ± 0.5
QRS duration, ms	145.6 ± 18.9
PQ interval, ms	198.2 ± 42.7
LBBB, n (%)	31 (59.6)
Heart disease	
Ischemic cardiomyopathy	6 (11.5)
Non-ischemic cardiomyopathy	46 (88.5)
Medication	
Beta-blocker	47 (90.4)
ACE/ARB	43 (82.7)
MRA	27 (51.9)
Comorbidity, n (%)	
Hypertension	26 (50.0)
Diabetes mellitus	20 (38.5)
Dyslipidemia	25 (48.1)
Chronic kidney disease	28 (53.8)

Note: Mean $\pm$ standard deviation.

Abbreviations: ACE, angiotensin converting enzyme; ARB, angiotensin receptor blocker; BNP, brain natriuretic peptide; LBBB, left bundle branch block; MRA, mineralocorticoid receptor antagonist; NYHA, New York Heart Association.

the dp/dt tended to be. However, there was no significant difference between any two pacing configurations. In three patients, stimulus-QRS duration was more than 40 ms.

3.2 | Acute differences between c-CRT and MPP and short AV delay and fused AV delay

MPP showed significant hemodynamic improvement and shortened QRS duration more than c-CRT (delta dp/dt: $10.5 \pm 1.0\%$ vs. $8.2 \pm 1.0\%$, *p* < 0.001, delta QRS duration: $-5.9 \pm 1.6\%$ vs. $-3.5 \pm 1.6\%$, *p* < 0.001, respectively). (Figure 1A,B). In 31 patients with LBBB, or in 21 patients with non-LBBB, MPP showed significant hemodynamic improvement and shortened QRS duration more than c-CRT. (Figure 2A,B).

The fused AV delay showed significant hemodynamic improvement and shortened QRS duration more than the short AV delay.

Pacing site	Delta dp/dt in c-CRT, %	Q-LV, ms	Pacing threshold, V at 0.4 ms	Pacing site	Delta dp/dt in MPP, %
1	7.6±11.4*	99.1±43.7	1.4±1.2	1-2	9.0±12.3
2	7.4±11.5	103.1±42.9	1.4±1.2	1-3	9.3±12.1
3	7.8±11.1*	105.5±44.6	1.7±1.3	1-4	9.2±12.0
4	6.1±12.0	105.9±46.4	2.5±1.6	2-3	9.0±10.7
				2-4	9.2±11.5
				3-4	8.2±11.5

Note: The value was mean±standard deviation. The delta dp/dt was significantly higher in electrode 1 or 3 than that of electrode 4.

Abbreviation: Q-LV, interval between onset of QRS and sensing at LV electrode.

* $p < 0.05$ compared to electrode 4.

TABLE 2 Electrical parameters in each pacing configuration of cCRT or MPP.

(delta dp/dt: $10.4 \pm 0.8\%$ vs. $8.3 \pm 1.1\%$, $p < 0.001$, delta QRS duration: $-10.2 \pm 1.2\%$ vs. $+0.7 \pm 1.8\%$, $p < 0.001$, respectively). (Figure 1C,D). In 31 patients with LBBB, the fused AV delay showed significant shortening of QRS duration, but not hemodynamic improvement more than the short AV delay (Figure 2C,D). In 21 patients with non-LBBB, the fused AV delay showed significant hemodynamic improvement and shortened QRS duration more than the short AV delay (Figure 2C,D).

3.3 | Acute effect of combining fused AV delay and MPP

Among the four categories (short AV delay + c-CRT, short AV delay + MPP, fused AV delay + c-CRT, and fused AV delay + MPP), fused AV delay + MPP showed significant hemodynamic improvement [fused AV delay + MPP ($12.1 \pm 1.2\%$) vs. short AV delay + c-CRT ($7.6 \pm 1.5\%$), $p < 0.0001$, vs. short AV delay + MPP ($9.6 \pm 1.7\%$), $p < 0.0001$, vs. fused AV delay + c-CRT ($9.7 \pm 1.1\%$), $p < 0.0001$] and shortened QRS duration [fused AV delay + MPP ($-12.0 \pm 1.6\%$) vs. short AV delay + c-CRT ($1.5 \pm 2.5\%$), $p < 0.0001$, vs. short AV delay + MPP ($-0.1 \pm 2.3\%$), $p < 0.0001$, vs. fused AV delay + c-CRT ($-8.7 \pm 1.5\%$), $p < 0.0001$] more than each other category. (Figure 1E,F).

3.4 | Acute differences between biventricular and LV pacing

In only 24 out of 52 patients, LV pacing was examined. LV pacing with MPP and fused AV delay significantly improved hemodynamics compared with BiV pacing with MPP and fused AV delay (delta dp/dt: $12.7 \pm 2.0\%$ vs. $11.3 \pm 1.5\%$, $p = 0.043$, respectively). (Figure 3A) However, the delta QRS duration was smaller in LV pacing with MPP and fused AV delay than that in BiV pacing with MPP and fused AV delay (delta QRS duration: $-5.4 \pm 2.4\%$ vs. $-16.1 \pm 1.5\%$, $p < 0.001$).

(Figure 3B) The AV delay in LV only pacing (second AV delay) was significantly shorter than that in BiV pacing (first AV delay) (154 ± 17.4 ms, vs. 219.6 ± 43.2 ms, $p < 0.001$).

3.5 | Correlation between delta dp/dt and delta QRS duration

The correlation coefficient between delta QRS duration and delta dp/dt max was inversely correlated with $R^2 = 0.3305$ ($p < 0.001$) for BiV pacing, suggesting that shortening the QRS duration may indicate hemodynamic improvement. Similarly, the correlation coefficient between delta QRS duration and delta dp/dt max was inversely correlated with $R^2 = 0.5319$ ($p < 0.001$) in LV pacing; however, the line differed from that in BiV pacing. For the same QRS shortening, delta dp/dt was greater with LV pacing than with BiV pacing; however, the difference was not statistically significant (Figure 4).

3.6 | 6 months after CRT implantation

Forty-one patients with active for the fused AV delay algorithm were followed for 6 months. Twenty-three (56.1%) out of 41 patients were active for the MPP because of high pacing threshold or phrenic nerve stimulation (Table 3). Among them, 27 (66%) were super-responders with LVESV reduced by more than 30%; six (15%) were responders with LVESV reduction from 15% to 29%; seven (19%) were non-responders (Figure 5).

4 | DISCUSSION

To the best of our knowledge, this is the first study to show the acute hemodynamic effects of the combination of MPP and fused AV delay. MPP or fused AV delay showed significant hemodynamic

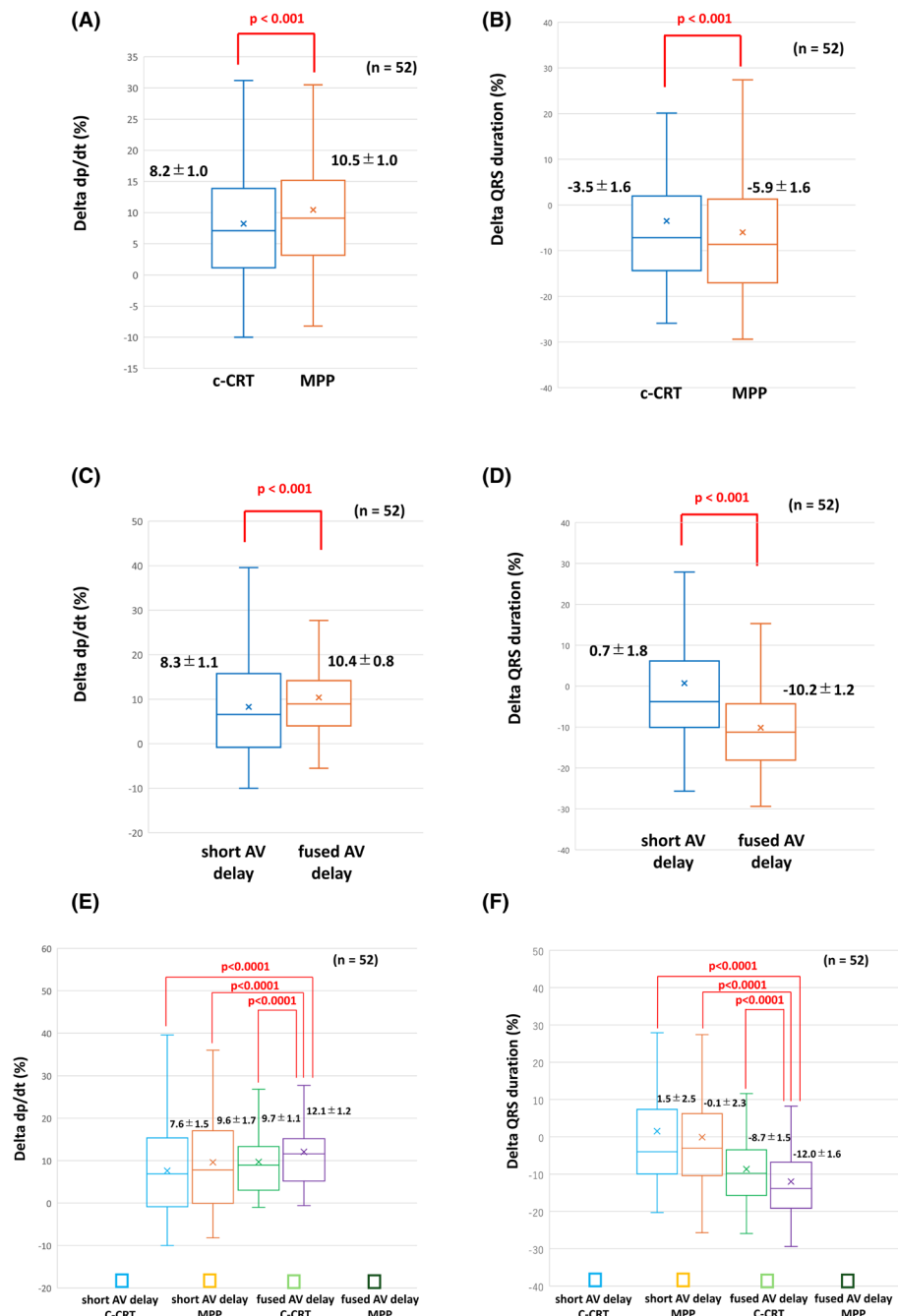


FIGURE 1 Delta dp/dt and delta QRS duration in each pacing configuration. (A) Delta dp/dt between conventional cardiac resynchronization therapy (c-CRT) and multipoint pacing (MPP), (B) Delta QRS duration between c-CRT and MPP, (C) Delta dp/dt between short AV delay and fused AV delay, (D) Delta QRS duration between short AV delay and fused AV delay, (E) Delta dp/dt among four categories, (F) Delta QRS duration among four categories.

improvement and shortened QRS compared to c-CRT or short AV delay. The same results were observed in patients with and without LBBB, except for delta dp/dt in patients with LBBB when comparing short AV delay and fused AV delay. Combining MPP and fused AV delay significantly improved the hemodynamics and shortened QRS duration compared to the other three categories. LV pacing with MPP and fused AV delay significantly improved hemodynamics compared with BiV pacing with MPP and fused AV delay. QRS shortening showed the inverse results. QRS duration was negatively associated

with dp/dt, but the approximate straight line differed between BiV and LV pacing. For the same QRS duration, delta dp/dt was greater with LV pacing than with BiV pacing.

4.1 | Multipoint pacing

Our findings were similar to those of a previous report demonstrating that MPP showed significantly better acute-phase

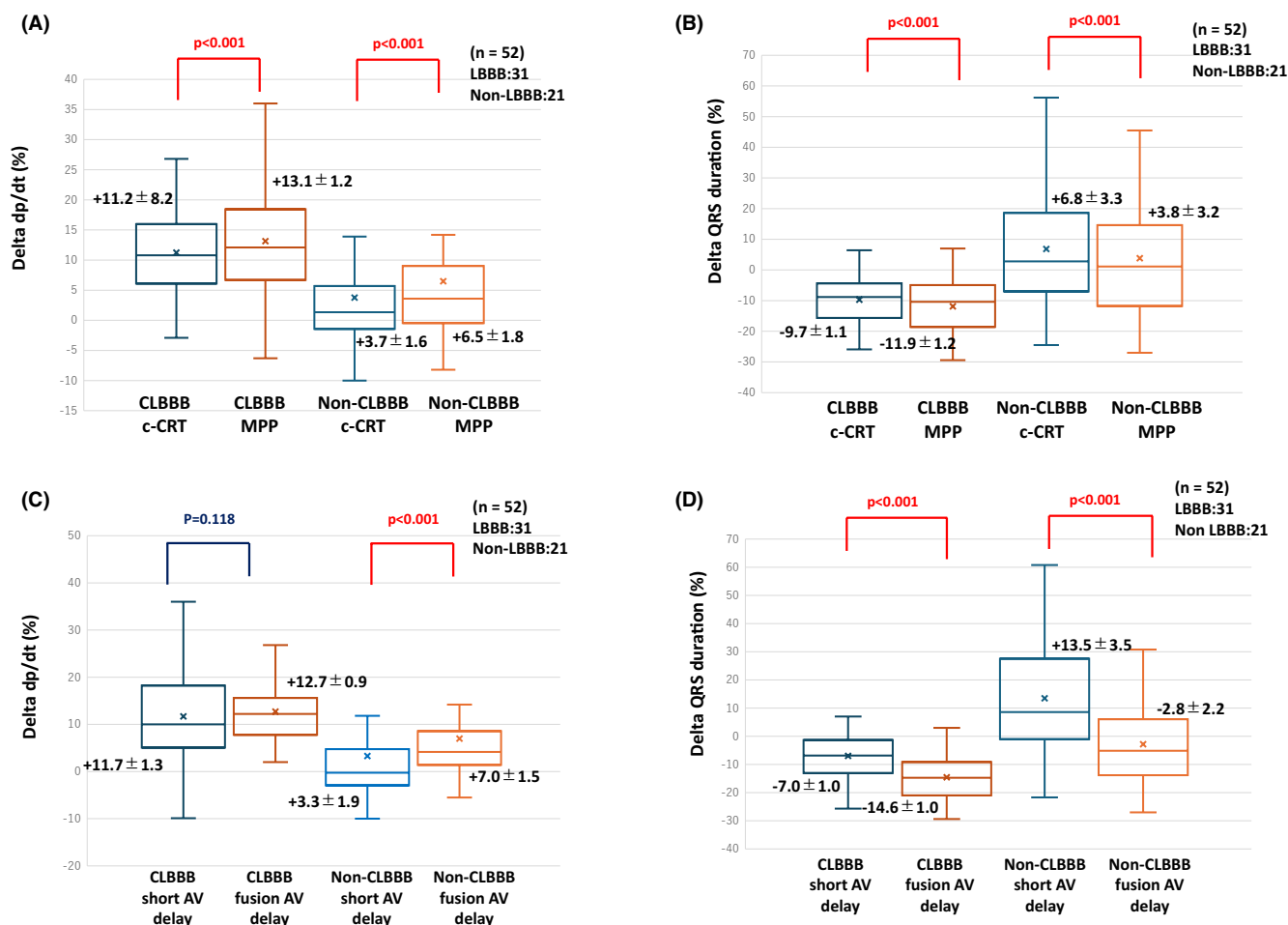


FIGURE 2 Delta dp/dt and delta QRS duration in each pacing configuration in patients with LBBB or non-LBBB. (A) Delta dp/dt between conventional cardiac resynchronization therapy (c-CRT) and multipoint pacing (MPP), (B) Delta QRS duration between c-CRT and MPP, (C) Delta dp/dt between short AV delay and fused AV delay, (D) Delta QRS duration between short AV delay and fused AV delay.

hemodynamic improvement than conventional CRT.⁸ Endri Menardi et al. also reported that MPP improved hemodynamics, shortened the total activation time of the LV endocardium, and narrowed the QRS duration compared to conventional CRT.¹⁰ In our study, QRS duration was significantly ($p < 0.001$) shorter with MPP than at baseline: -9.8% with MPP and -6.4% with conventional CRT ($p < 0.001$). This suggests that in addition to the improvement in mechanical dyssynchrony, improvement in electrical dyssynchrony was also obtained.

Chronic effects have also been reported, but the findings are controversial.^{11,24–28} Pappone et al.¹¹ showed that responder and super-responder rates were higher with MPP than with conventional CRT in a few patients. Forleo et al.²⁵ reported more improvement in the clinical composite score of patients with MPP-ON than in controls. However, a study²⁷ reported no significant benefit of MPP compared with conventional CRT. In a meta-analysis,²⁹ MPP was more efficacious in non-randomized studies and not superior when assessed in randomized studies. In our study, even when MPP was more effective, it was not turned on in all patients because of a high pacing threshold or diaphragmatic nerve stimulation. There was no

significant difference in the response rates between MPP and c-CRT among the 41 patients (data not shown).

The acute study was conducted to achieve a super-responder rather than a responder, and the highest delta dp/dt was set based on the results of the study. However, battery depletion is considered a negative aspect of MPP. Therefore, if the pacing threshold is high, c-CRT is selected even if MPP has a high delta dp/dt. If the results of delta dp/dt between c-CRT and MPP were the same, c-CRT was selected. To reduce battery drain, the output of the second LV pacing site has a smaller margin. We have not experienced any cases of extreme battery degradation with this approach.

4.2 | Fused AV delay

Varma et al.¹⁶ reported that a customized fused AV delay showed the narrowest QRS duration. In this study, we found a significant reduction of -10.2% in the fusion AV delay group and 0.7% in the short AV delay group compared with baseline ($p < 0.001$). Although the QRS duration has been known to shorten when used with

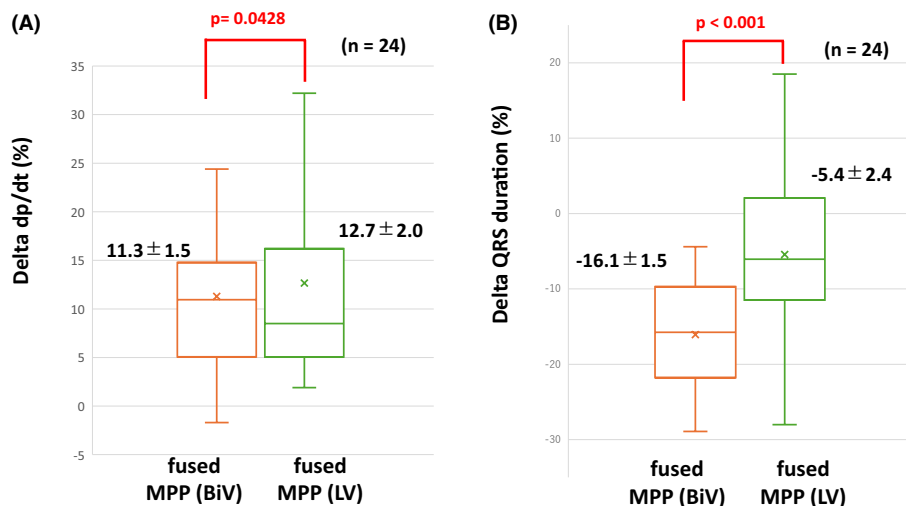


FIGURE 3 Delta dp/dt and delta QRS duration between biventricular pacing and LV pacing with fused AV delay. (A) Delta dp/dt between biventricular (BiV) and LV pacing with fused AV delay and multipoint pacing (MPP). (B) Delta QRS duration between BiV and LV pacing with fused AV delay and MPP.

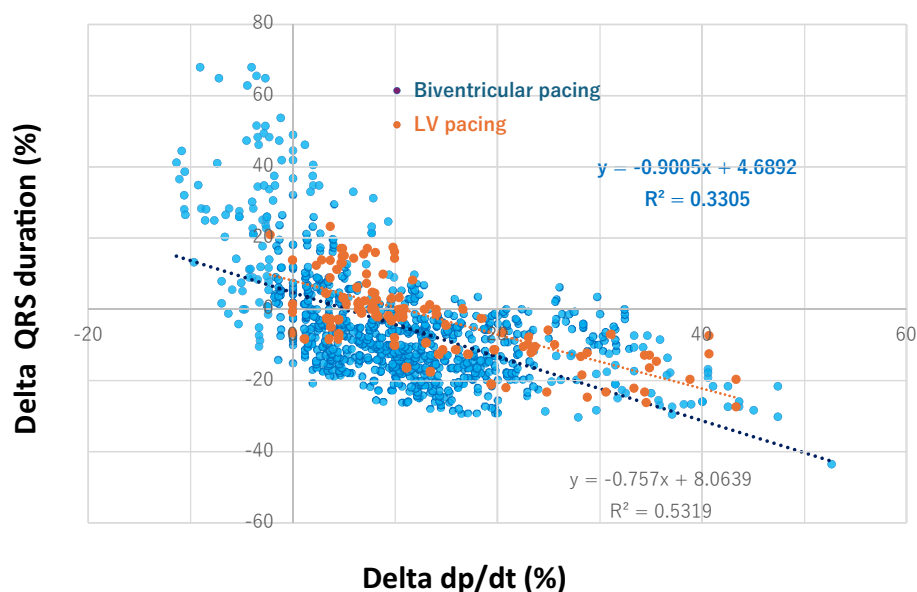


FIGURE 4 Correlation between delta dp/dt and delta QRS duration. The correlation coefficient between delta QRS duration and delta dp/dt was inversely correlated with biventricular and LV pacing.

fusion AV delay, to date, no reports have evaluated the relationship between QRS duration and hemodynamics in fused AV delay. In our study, fused AV delay showed significant hemodynamic improvement and shortened QRS compared with short AV delay.

Regarding chronic effects, some reports have demonstrated the benefits of fused AV delay.^{18–20} In a recent large randomized study,²⁰ fused AV delays did not reduce the incidence of all-cause death or intervention for HF decompensation. However, all-cause mortality or HF intervention was significantly lower in patients with adaptive CRT and $\geq 85\%$ LV pacing than in the other categories. Consistent with previous studies, our study showed a high

super-responder rate (66%) in patients undergoing CRT with fused AV delay with or without MPP.

4.3 | Combining MPP and fused AV delay

Reports on MPP and fused AV delay are limited.^{21,22} Schiedat et al.²¹ demonstrated that the QRS duration was shortest when MPP and fused AV delay were combined. Similar results were obtained in this study. Additionally, the hemodynamic effect was best when MPP and fused AV delay were combined.

TABLE 3 Characteristics of patients with automatic fused AV delay.

	Total
N	41
Male, n (%)	27 (63.4)
Age, years	68.4 ± 10.2
NYHA class, n (%)	
I	0 (0)
II	19 (46.3)
III	18 (43.9)
IV	4 (9.8)
Ejection fraction, %	29.9 ± 7.6
Log BNP	2.0 ± 0.4
QRS duration, ms	145.4 ± 20.0
PQ interval, ms	198.2 ± 42.0
LBBB, n (%)	26 (63.4)
MPP, n (%)	23 (56.1)
Heart disease	
Ischemic cardiomyopathy	6 (14.6)
Non-ischemic cardiomyopathy	35 (85.3)
Medication	
Beta-blocker	37 (90.2)
ACE/ARB	34 (82.9)
MRA	23 (56.1)
Comorbidity, n (%)	
Hypertension	18 (43.9)
Diabetes mellitus	14 (34.1)
Dyslipidemia	19 (46.3)
Chronic kidney disease	23 (56.1)

Note: Mean ± standard deviation.

Abbreviations: ACE, angiotensin converting enzyme; ARB, angiotensin receptor blocker; BNP, brain natriuretic peptide; LBBB, left bundle branch block; MPP, multipoint pacing; MRA, mineralocorticoid receptor antagonist; NYHA, New York Heart Association.

4.4 | Correlation between delta dp/dt and delta QRS duration: BiV And LV pacing

The rates of change in delta dp/dt and QRS duration are inversely correlated, and shortening the QRS duration can be a predictor of hemodynamic improvement, as reported by Korantzopoulos et al.³⁰ This result was also confirmed for LV pacing; however, there was a significant difference in the degree of shortening of the QRS duration compared with BiV pacing. Delta dp/dt was greater during LV pacing than during BiV pacing. However, delta QRS duration was shorter with LV pacing than with BiV pacing. The intrinsic conduction of the right bundle branch may contribute to a higher delta dp/dt compared to RV pacing. LV pacing resulted in better hemodynamic improvement than BiV pacing; however, shortening of the QRS duration was less pronounced. Therefore, caution should be exercised when comparing BiV pacing with LV pacing because a shorter QRS duration

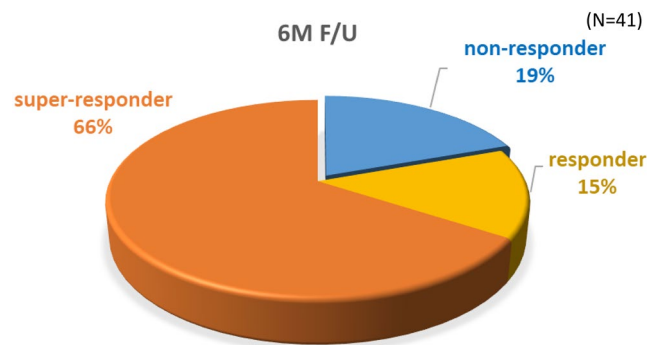


FIGURE 5 Responder rate after CRT implantation. The response rate after 6 months in patients with pacing site optimization using the mounted auto-fusion AV delay function in the device was evaluated by left ventricular end-systolic volume (LVESV) change on ultrasound cardiography. The results showed that 66% of super-responders and 15% of responders, making a total of 81%, had a good response.

does not always indicate hemodynamic improvement. However, the AV delay in LV pacing was significantly shorter than that in BiV pacing because of differences in the calculation algorithm. If the AV delay were similar, the results might be different. Clinically, all-cause mortality or HF intervention was significantly lower in patients with adaptive CRT and >85% LV pacing than in other categories.²⁰

4.5 | Super-responders in the chronic phase

Super-responders reportedly have additional benefits, such as reduced HF hospitalization, appropriate ICD therapy rate, or mortality.^{31–33} Directions to aim for CRT may include super-responders rather than just responders. In our study, the super-responder rate was 66% with MPP and fused AV delay or c-CRT and fused AV delay. Combining MPP and fused AV delay may cause additional chronic effects.

4.6 | Limitations

First, hemodynamic changes were assessed during the acute phase of CRT device implantation but not in the chronic phase. Second, this was a retrospective, single-center study with a small sample size. In the future, prospective multicenter studies with more patients are needed to confirm these results.

5 | CONCLUSIONS

MPP or a fused AV delay can improve hemodynamics compared with c-CRT or a short AV delay. Combining MPP and fused AV delay significantly improves hemodynamics. QRS shortening can predict increased dp/dt; however, the effect was not the same between LV and BiV pacing.

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CONFLICT OF INTEREST STATEMENT

Nobuhiro Nishii and Hiroshi Morita belong to the endowed department of Medtronic. Nobuhiro Nishi received lecture fees from Medtronic Japan Co., Ltd. and Boston Scientific Japan. None of the other authors have any additional relationships with the industry.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author [NN] upon reasonable request.

ETHICS STATEMENT

The research protocol received approval from the ethics committee at Okayama University Hospital and adhered to the principles outlined in the Declaration of Helsinki. Written informed consent was waived because of the retrospective study design.

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