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# Cardiac resynchronization therapy improves left ventricular remodeling and function compared with right ventricular pacing in patients with atrioventricular block

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**Abstract**
Right ventricular pacing (RVP) exerts a detrimental effect on left ventricular (LV) remodeling. In patients with atrioventricular block (AVB) that require ventricular pacing, the effect of biventricular pacing (BiVP) versus RVP on LV remodeling and function has not been comprehensively assessed in a meta-analysis. Electric databases MEDLINE and Cochrane Library were retrieved for randomized controlled trials (RCT) comparing RVP and BiVP in patients with AVB. Data on left ventricular ejection fraction (LVEF) and LV volumes were analyzed, stratified by different time points. Eleven RCTs were included in the final analysis. There was a significant reduction of LV end-systolic volume in BiVP compared with RVP, at 3, 6, 12, and 24 months follow-up ($P < 0.05$ for all). BiVP was associated with a decreased LV end-diastolic volume in comparison to RVP at 3, 6, and 12 months. Compared with RVP, BiVP had a higher LVEF at all follow-up visits, with mean difference of 5.91, 3.29, 3.9, 6.66, and 8.69% at 3, 6, 12, 24, and beyond 24 months follow-up, respectively. The results were not significantly changed in sensitivity analysis after removal of studies with mean baseline LVEF < 50% or excluding studies with ablation-induced AVB. In patients with AVB and bradycardia that require ventricular pacing, BiVP is superior to RVP in improving LV remodeling and function.

**Keywords** Cardiac resynchronization therapy · Atrioventricular block heart failure · Cardiac remodeling

## Introduction

In patients with standard pacing indications, right ventricular pacing (RVP) is commonly chosen for its relatively good stability. However, emerging trials have revealed that RVP exerts a detrimental effect on left ventricular (LV) function and remodeling [1, 2]. As a result, RVP has been linked to increased risks of heart failure (HF) [3, 4]. The non-physiological asynchronous contraction following RVP accounts for its adverse cardiovascular effects. One potential solution is to minimize the frequency of RVP, but this does not work in heart block [5]. Another approach is the use of biventricular pacing (BiVP) to attenuate ventricular dyssynchrony. Cardiac resynchronization therapy (CRT) is mainly investigated and recommended in patients with severely reduced left ventricular ejection fraction (LVEF) and complete left bundle branch block [6]. Previous studies have demonstrated that CRT was better than RVP in patients undergoing atrialventricular junction ablation for atrial fibrillation [7–9]. Whether BiVP is superior to RVP in intrinsic atrioventricular block (AVB) has also been proposed and tested in several individual randomized trials [10–13]. We conducted this study to comprehensively appraise the effect of BiVP versus RVP on LV remodeling and function, in patients with ablation-induced or intrinsic AVB that require ventricular pacing.

Dasheng Lu and Hao Zhang contributed equally to this work.

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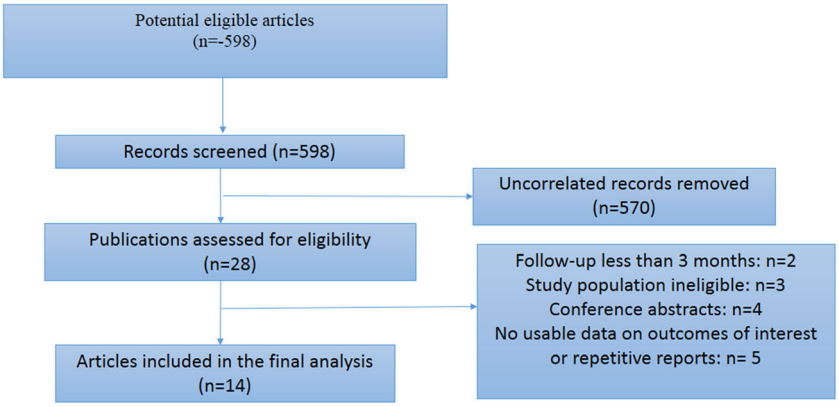


**Fig. 1** Flow chart of literature search and selection

## Methods

This study is performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [14].

### Literature search

We searched electric databases MEDLINE and Cochrane Library for relevant randomized controlled trials (RCTs), from inception through February 2, 2017. The following keywords were applied: (i) "atrioventricular block" or "AV block" or "AVB" and (ii) "cardiac resynchronization therapy" or "biventricular pacing" or "biventricular". "Catheter ablation" and "atrial fibrillation" were also used to identify studies with atrioventricular nodal ablation-induced AVB. Relevant references were scanned for possible eligibility. No language restriction was used. The search was conducted by two independent investigators (D.S.L. and H.Z.).

The titles and abstracts of retrieved articles were scanned. Only RCTs comparing BiVP and RVP in patients with AVB were considered eligible. The exclusion criteria include (1) no RCTs, (2) no data on primary or secondary endpoints or reported data cannot be analyzed, and (3) follow-up visit less

**Table 1** Baseline characteristics of included studies

| Study (first author) | Year | Arms | FU (months) | NO. | Age (yrs) | Female (%) | Mean baseline LVEF < 50% | JADAD quality | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Randomization | Blinding | Drop-outs |
| Cross-over RCTs | | | | | | | | | | |
| HOBIPACE (Kindermann) | 2006 | RVP → BiVP | 3 | 30 | 69.6 | 23 | Yes | Yes | Single-blinded | Yes |
| OPSITE (Brignole)* | 2005 | RVP → BiVP | 3 | 56 | 70 | 39 | Yes | Yes | Single-blinded | Yes |
| COMBAT | 2010 | RVP | 3 | 31 | 57.4 | 32.3 | Yes | Yes | Double-blinded | Yes |
| (Martinelli) | | BiVP | 3 | 29 | 59.3 | 37.9 | Yes | | | |
| Parallel RCTs | | | | | | | | | | |
| PAVE (Doshi)* | 2005 | RVP | 6 | 106 | 67 | 36 | Yes | Yes | Single-blinded | Yes |
| | | BiVP | 6 | 146 | 70 | 37 | Yes | | | |
| (Albertsen) | 2008 | RVP | Multiple | 25 | 76 | 32 | No | Yes | Single-blinded | Yes |
| | | BiVP | Multiple | 25 | 76 | 32 | No | | | |
| PACE (Yu, C) | 2009 | RVP | Multiple | 88 | 68 | 44 | No | Yes | Double-blinded | Yes |
| | | BiVP | Multiple | 89 | 69 | 47 | No | | | |
| APAF(Brignole)* | 2011 | RVP | 24 | 89 | 72 | 27 | Yes | Yes | Yes | Yes |
| | | BiVP | 24 | 97 | 72 | 33 | Yes | | | |
| AVAIL (Orlov)* | 2010 | RVP | 12 | 20 | 70.1 | 35 | No | Yes | Single-blinded | Yes |
| | | BiVP | 12 | 88 | 73.0 | 60 | No | | | |
| PREVENT-HF | 2011 | RVP | 12 | 58 | 69.5 | 24 | No | Yes | Double-blinded | Yes |
| (Stockburger) | | BiVP | 12 | 50 | 71.6 | 32 | No | | | |
| BLOCK HF | 2013 | RVP | Multiple | 342 | 73 | 27.2 | Yes | Yes | Double-blinded | Yes |
| (Curtis) | | BiVP | Multiple | 349 | 73.7 | 23.2 | Yes | | | |
| BIVPACE-AVB | 2016 | RVP | 12 | 57 | 66 | 29.8 | No | Yes | Double-blinded | Yes |
| (Zhang) | | BiVP | 12 | 57 | 67.1 | 28.1 | No | | | |

Data were mean ± SD or median (25th, 75th). *RCTs*, randomized controlled trials; *RVP*, right ventricular pacing; *BivP*, biventricular pacing; *FU*, follow-up; *NO.*, number of patients; *yrs*, years; *LVEF*, left ventricular ejection fraction; *NA*, not available. Asterisk indicates studies in which patients underwent atrioventricular junction or his bundle ablation

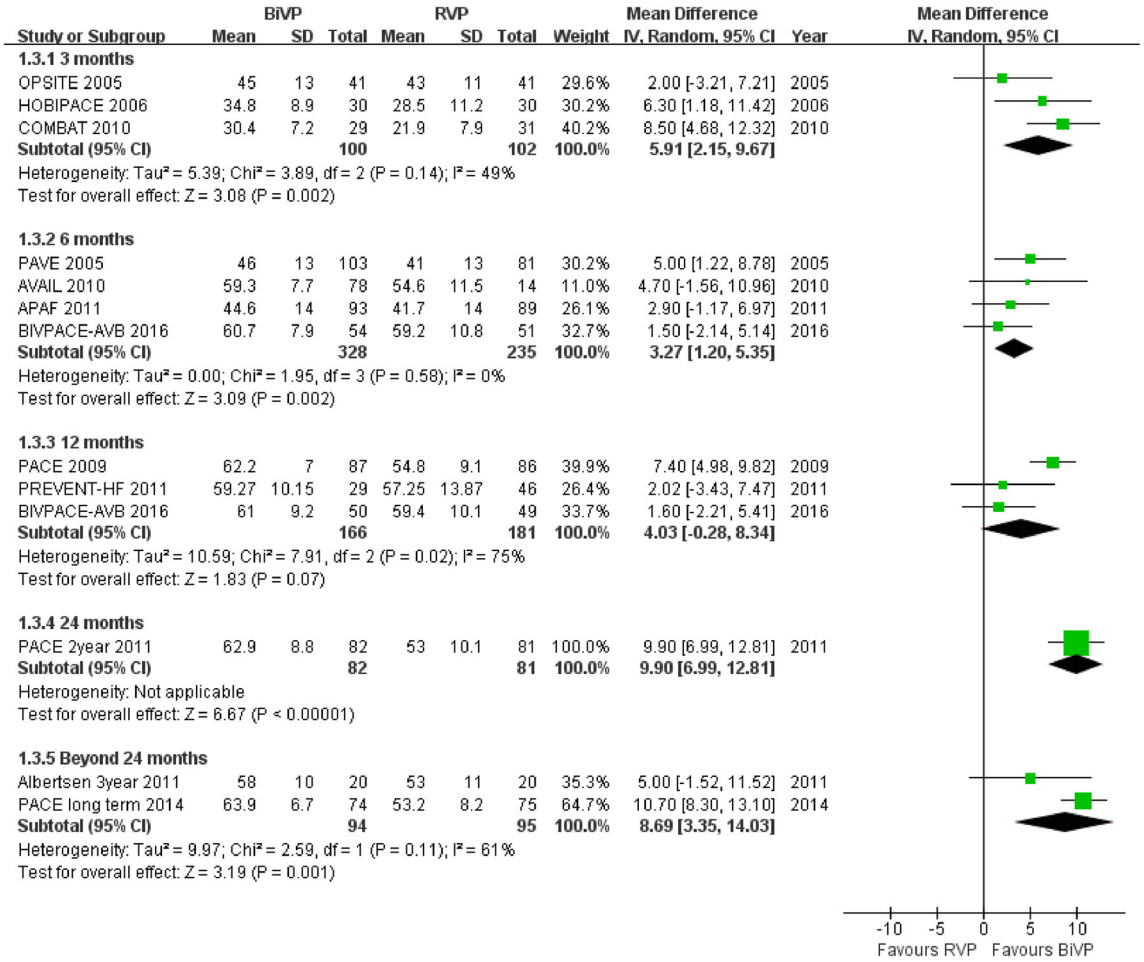


**Fig. 2** Forest plot of final value of left ventricular ejection fraction (LVEF) associated with biventricular versus right ventricular pacing, stratified by follow-up time points

than 3 months. Conference abstracts were also excluded. Then, the full texts of remaining articles were further checked for eligibility. Extra attention was focused on various articles regarding one trial, with the aims to gather data at different follow-up visits.

## Data extraction and endpoints

Data were extracted by two independent reviewers (D.S.L. and K.W.). The primary endpoint was LVEF. The secondary endpoints were LV volumes. Continuous data were collected and analyzed, stratified by follow-up durations. With respect to cross-over RCTs, data of the first phase were collected and analyzed if available. The quality of included RCTs was assessed by means of JADAD criteria (randomization, blinding, and description of withdrawals or dropouts).

## Statistics

Continuous data were expressed as mean ± standard deviance (SD). We primarily extracted and pooled data on final value outcomes. As a complementarity, the differences in change from baseline were also calculated. If the SD of change was not available, imputed correlation coefficients were adopted and tested in necessary sensitivity analyses. Skewed data (expressed as median) were not included in the pooled analyses but were described in the text. We applied weighted mean difference (WMD) and its 95% confidence interval (CI) to reflect the effect size. $I^2$ was adopted to evaluate the between-study heterogeneity. A random-effects model was employed when $I^2 > 50\%$. We also conducted sensitivity analyses by excluding studies with mean baseline LVEF < 50% or removing studies with ablation-induced AVB. We used Review Manager (version 5.2), Comprehensive Meta-Analysis (Version 2.0), and STATA (version 12.0) to perform pooled analysis. A $P$ value less than 0.5 was considered of statistical significance.

## Results

In total, 14 articles involving 11 RCTs were included in this systematic review [7, 9–11, 13, 15–23], according to

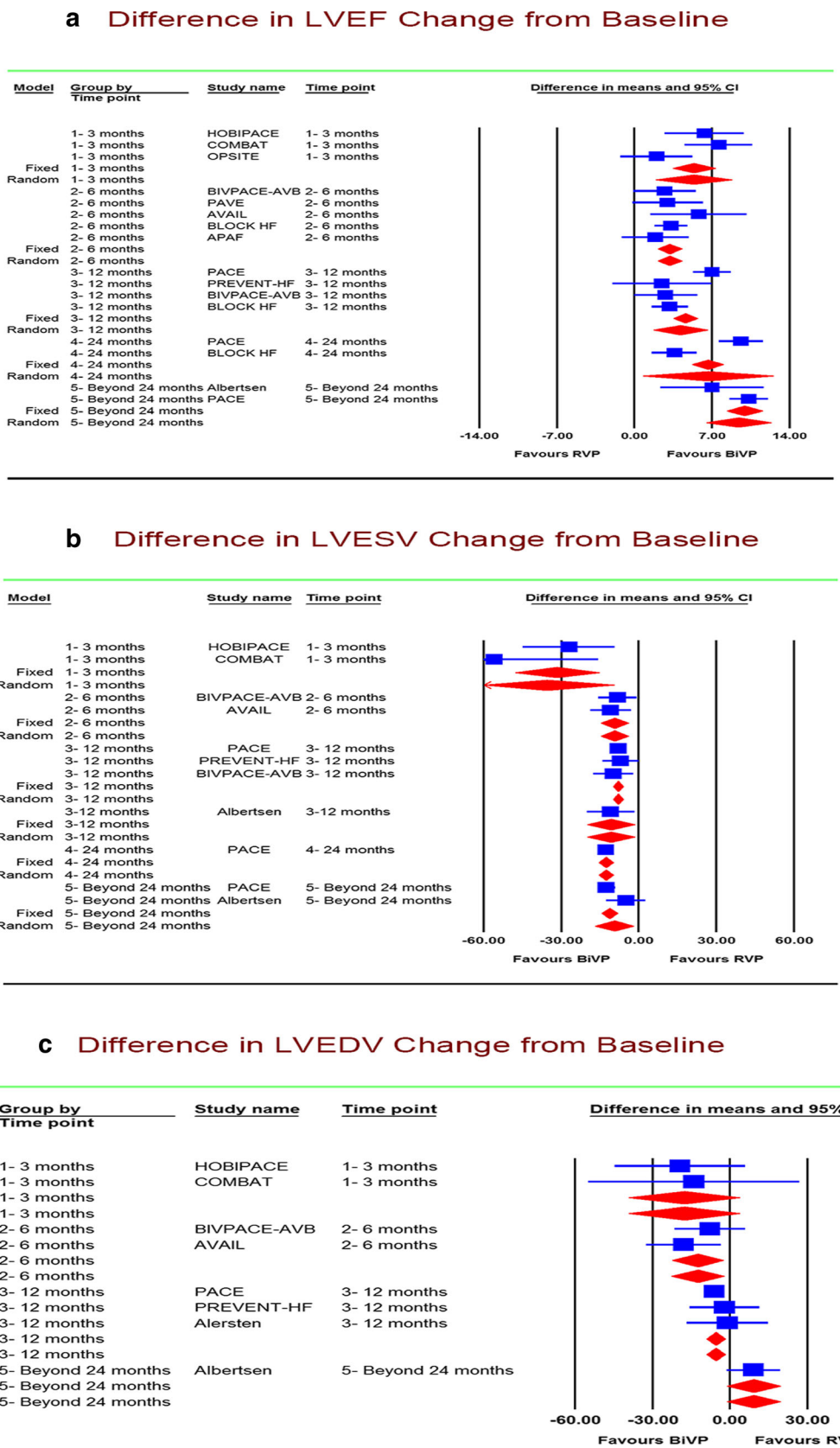


**Fig. 3** Forest plot of change from baseline of (A) left ventricular ejection fraction, (B) left ventricular end-systolic volume and (C) left ventricular end-diastolic volume, associated with biventricular versus right ventricular pacing, stratified by follow-up time points

our pre-defined inclusion criteria (Fig. 1). Baseline characteristics of included studies were shown in Table 1. Generally, all the studies were of good quality. There were three studies featuring a cross-over design [7, 10, 17]. Study population of four trials were those who underwent atrioventricular nodal ablation for atrial fibrillation [7, 9, 15, 18]. The remaining seven trials involved patients with intrinsic AVB that require ventricular pacing. Six studies featured a mean baseline LVEF less than 50% [7, 9, 10, 15, 17, 22]. Patient mean age varied 57.4 to 76 years. Follow-up durations varied from 3 months to more than 36 months. We pooled outcomes of interest at different time points, including 3, 12, 24, and beyond 24 months.

## Left ventricular ejection fraction

Compared with RVP, BiVP had a higher LVEF at all follow-up visits, with WMD of 5.91% (95% CI 2.14 to 9.18%), 3.29% (95% CI 2.09 to 4.49%), 3.90% (95% CI 1.15 to 6.65%), 6.66% (95% CI 0.49 to 12.83%), and 8.69% (95% CI 3.35 to 14.03%) at 3, 6, 12, 24, and beyond 24 months, respectively (Fig. 2). With respect to difference in change from baseline, BiVP treatment was also superior to RVP, with WMD of 5.31% (95% CI 1.91 to 8.71%), 3.15% (95% CI 2.07 to 4.22%), 4.12% (95% CI 1.69 to 6.56%), 6.60% (95% CI 0.72 to 12.48%), and 9.39% (95% CI 6.50 to 12.28) at 3, 6, 12, 24, and beyond 24 months, respectively (Fig. 3a).

## Left ventricular volumes

Pooled analysis suggested that BiVP was associated with a significant reduction of LV end-systolic volume (LVESV) compared with RVP, with WMD of −47.22, −7.57, and −13.00 ml at 3, 6, 12, and 24 months, respectively ($P < 0.05$ for all) (Fig. 4). Similarly, LV end-diastolic volume (LVEDV) was also significantly decreased in BiVP in comparison to RVP at 3 months (WMD = −27.46 ml, 95% CI −0.53 to −54.38 ml), 6 months (WMD = −19.97 ml, 95% CI −35.85 to −4.1 ml), and

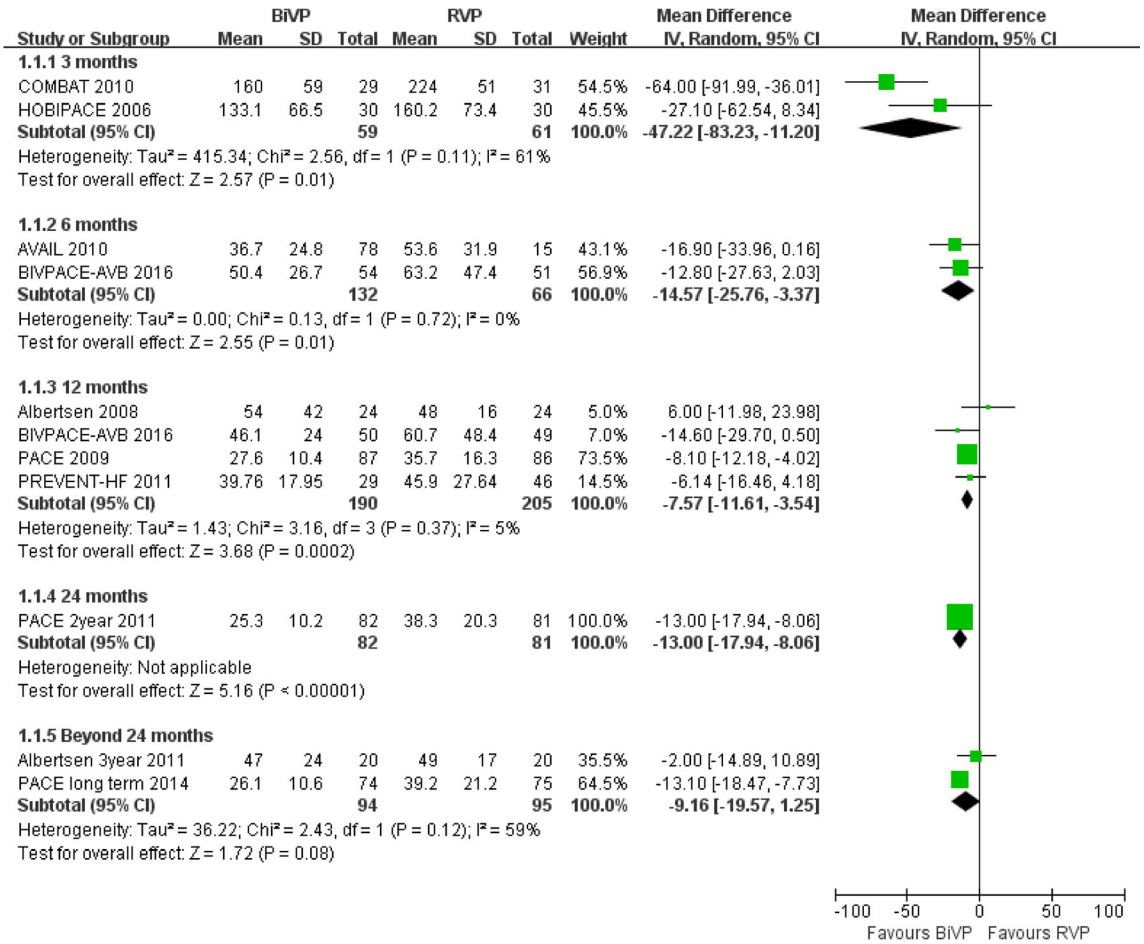


**Fig. 4** Forest plot of final value of left ventricular end-systolic volume associated with biventricular versus right ventricular pacing, stratified by follow-up time points

12 months (WMD = − 5.57 ml, 95% CI − 0.29 to − 10.84 ml), respectively (Fig. 5). Pooled data on change from baseline showed similar results (Fig. 3b, c).

## Other LV remodeling-related indices

LV volumes indexed to body surface (LVEDVi and LVESVi) were reported in the BLOCK-HF trial [22]. Consistently, BiVP led to more evident reduction in LVEDVi and LVESVi, compared with RVP. N-terminal pro brain natriuretic peptide (NT-ProBNP) was also measured in several trials. In the study by Albertsen et al. [16], NT-ProBNP significantly decreased following BiVP, whereas unchanged in RVP at 12 months. Similarly, in the study of Zhang [23], NT-ProBNP significantly increased in RVP but not in BiVP ($P > 0.05$), compared with baseline.

## Sensitivity analysis

The results were not significantly changed in sensitivity analysis excluding studies with ablation-induced AVB (Supplementary Table 1). After removal of studies with mean baseline LVEF < 50%, however, we found that the difference in LVEF became non-significant at 6 and 12 months (Supplementary Table 1).

## Discussion

The electrocardiogram pattern following RVP is similar to that in intrinsic LBBB, which indicates the presence of LV dyssynchrony. RVP could lead to LV structural and functional abnormalities as well as clinical HF events [4, 24, 25]. Reducing unnecessary RV pacing is adopted to prevent adverse outcomes [26]. However, this strategy may be feasible only in intact atrioventricular conduction but not in AVB. Especially in patients with complete or high-grade AVB, ventricular pacing may be needed most of the time. BiVP could minimize the LV asynchrony and thus improve HF manifestation as well as survival rate in patients with reduced LVEF and prolonged QRS complex [27, 28]. Therefore, BiVP has the potential to substitute RVP in patients with AVB. Previous meta-analyses have revealed that BiVP is superior to RVP in patients who underwent atrioventricular nodal ablation for atrial arrhythmias [8, 29]. However, these previous meta-analyses did not include intrinsic AVB, a much more common condition that had similar electrophysiological characteristic to ablation-induced AVB. Differing from prevenient meta-analyses, the present study was based on patients with intrinsic AVB as well as ablation-induced AVB. Using sensitivity analysis, we found that the results were not significantly changed even if those with ablation-induced AVB were excluded.

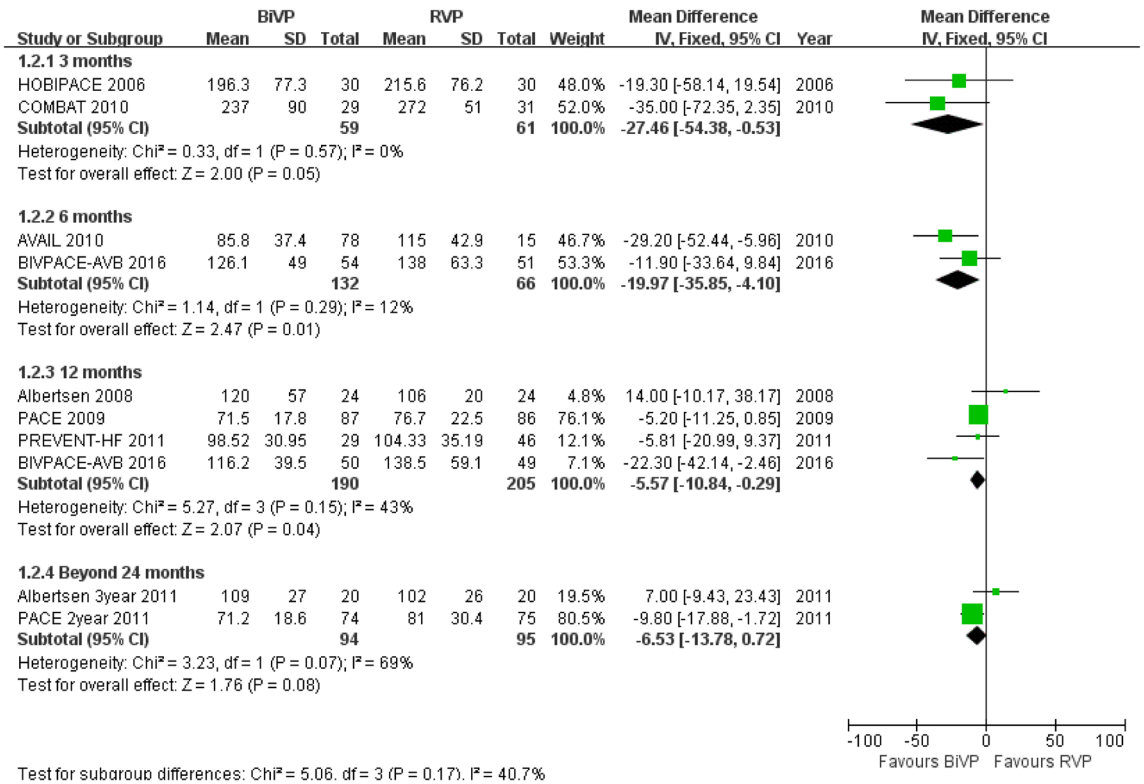


**Fig. 5** Forest plot of final value of left ventricular end-diastolic volume associated with biventricular versus right ventricular pacing, stratified by follow-up time points

In consideration of the presence of time-dependent effect, we reported data stratified by different follow-up times. Our analysis showed that BiVP was linked to reduced LV volumes and improved LVEF at both short- (3 months) and long-term (up to 24 months) follow-up. As indicated by the DAVID trial [25] and MOST trial [4], patients with poor baseline LVEF may suffer more from RV pacing. Sensitivity analysis found that the difference in LVEF became non-significant at 6 and 12 months after removal of studies with mean baseline LVEF < 50%, indicating that the superiority of BiVP might be more evident in patients with reduced LVEF than in those with normal LVEF.

Patients in all included studies had underwent randomization, so there was no significant between-group difference in LVEF or LV volumes at baseline. Hence, it is reasonable to compare final values of outcomes of interest. Pooled analyses of data on change from baseline also showed the superiority of BiVP over RVP, suggesting the results are robust.

## Limitations

Several limitations should be discussed. Firstly, the relatively small number of included studies might lead to underpowered analyses, in particular, when we divided them into different subgroup analyses. Publication bias cannot be excluded due to the small sample size. Secondly, although we have performed some subgroup analyses (stratified by follow-up duration), the heterogeneity remained significant in several analyses. This may be generated from the variety in study population, baseline characteristics, and study quality.

## Conclusion

In patients with AVB that require ventricular pacing, BiVP is associated with improvements in LV remodeling and function, compared with RVP.

### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** This article does not contain any studies with human participants or animals performed by any of the authors.

## References


1. Tse HF, Yu C, Wong KK, Tsang V, Leung YL, Ho WY, Lau CP (2002) Functional abnormalities in patients with permanent right ventricular pacing: the effect of sites of electrical stimulation. J Am Coll Cardiol 40(8):1451–1458
2. Nielsen JC, Andersen HR, Thomsen PE, Thuesen L, Mortensen PT, Vesterlund T, Pedersen AK (1998) Heart failure and echocardiographic changes during long-term follow-up of patients with sick sinus syndrome randomized to single-chamber atrial or ventricular pacing. Circulation 97(10):987–995
3. Zhang XH, Chen H, Siu CW, Yiu KH, Chan WS, Lee KL, Chan HW, Lee SW, Fu GS, Lau CP, Tse HF (2008) New-onset heart failure after permanent right ventricular apical pacing in patients with acquired high-grade atrioventricular block and normal left ventricular function. J Cardiovasc Electrophysiol 19(2):136–141. https://doi.org/10.1111/j.1540-8167.2007.01014.x
4. Sweeney MO, Hellkamp AS, Ellenbogen KA, Greenspon AJ, Freedman RA, Lee KL, Lamas GA (2003) Adverse effect of ventricular pacing on heart failure and atrial fibrillation among patients with normal baseline QRS duration in a clinical trial of pacemaker therapy for sinus node dysfunction. Circulation 107(23):2932–2937. https://doi.org/10.1161/01.cir.0000072769.17295.b1
5. Sharma AD, Rizo-Patron C, Hallstrom AP, O'Neill GP, Rothbart S, Martins JB, Roelke M, Steinberg JS, Greene HL (2005) Percent right ventricular pacing predicts outcomes in the DAVID trial. Heart Rhythm 2(8):830–834. https://doi.org/10.1016/j.hrthm.2005.05.015
6. Abraham WT, Fisher WG, Smith AL, Delurgio DB, Leon AR, Loh E, Kocovic DZ, Packer M, Clavell AL, Hayes DL, Ellestad M, Trupp RJ, Underwood J, Pickering F, Truex C, McAtee P, Messenger J (2002) Cardiac resynchronization in chronic heart failure. N Engl J Med 346(24):1845–1853. https://doi.org/10.1056/NEJMoa013168
7. Brignole M, Gammage M, Puggioni E, Alboni P, Raviele A, Sutton R, Vardas P, Bongiorni MG, Bergfeldt L, Menozzi C, Musso G (2005) Comparative assessment of right, left, and biventricular pacing in patients with permanent atrial fibrillation. Eur Heart J 26(7):712–722. https://doi.org/10.1093/eurheartj/ehi069
8. Stavrakis S, Garabelli P, Reynolds DW (2012) Cardiac resynchronization therapy after atrioventricular junction ablation for symptomatic atrial fibrillation: a meta-analysis. Europace 14(10):1490–1497. https://doi.org/10.1093/europace/eus193
9. Brignole M, Botto G, Mont L, Iacopino S, De Marchi G, Oddone D, Luzi M, Tolosana JM, Navazio A, Menozzi C (2011) Cardiac resynchronization therapy in patients undergoing atrioventricular junction ablation for permanent atrial fibrillation: a randomized trial. Eur Heart J 32(19):2420–2429. https://doi.org/10.1093/eurheartj/ehr162
10. Kindermann M, Hennen B, Jung J, Geisel J, Bohm M, Frohlig G (2006) Biventricular versus conventional right ventricular stimulation for patients with standard pacing indication and left ventricular dysfunction: the Homburg Biventricular Pacing Evaluation (HOBIPACE). J Am Coll Cardiol 47(10):1927–1937. https://doi.org/10.1016/j.jacc.2005.12.056
11. Yu CM, Chan JY, Zhang Q, Omar R, Yip GW, Hussin A, Fang F, Lam KH, Chan HC, Fung JW (2009) Biventricular pacing in patients with bradycardia and normal ejection fraction. N Engl J Med 361(22):2123–2134. https://doi.org/10.1056/NEJMoa0907555
12. Curtis AB, Worley SJ, Adamson PB, Chung ES, Niazi I, Sherfesee L, Shinn T, Sutton MS (2013) Biventricular pacing for atrioventricular block and systolic dysfunction. N Engl J Med 368(17):1585–1593. https://doi.org/10.1056/NEJMoa1210356
13. Stockburger M, Gomez-Doblas JJ, Lamas G, Alzueta J, Fernandez-Lozano I, Cobo E, Wiegand U, Concha JF, Navarro X, Navarro-Lopez F, de Teresa E (2011) Preventing ventricular dysfunction in pacemaker patients without advanced heart failure: results from a multicentre international randomized trial (PREVENT-HF). Eur J Heart Fail 13(6):633–641. https://doi.org/10.1093/eurjhf/hfr041
14. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, Clarke M, Devereaux PJ, Kleijnen J, Moher D (2009) The PRISMA statement for reporting systematic reviews

and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med 6(7):e1000100. https://doi.org/10.1371/journal.pmed.1000100

15. Doshi RN, Daoud EG, Fellows C, Turk K, Duran A, Hamdan MH, Pires LA (2005) Left ventricular-based cardiac stimulation post AV nodal ablation evaluation (the PAVE study). J Cardiovasc Electrophysiol 16(11):1160–1165. https://doi.org/10.1111/j.1540-8167.2005.50062.x
16. Albertsen AE, Nielsen JC, Poulsen SH, Mortensen PT, Pedersen AK, Hansen PS, Jensen HK, Egeblad H (2008) Biventricular pacing preserves left ventricular performance in patients with high-grade atrio-ventricular block: a randomized comparison with DDD(R) pacing in 50 consecutive patients. Europace 10(3):314–320. https://doi.org/10.1093/europace/eun023
17. Martinelli Filho M, de Siqueira SF, Costa R, Greco OT, Moreira LF, D'Avila A, Heist EK (2010) Conventional versus biventricular pacing in heart failure and bradyarrhythmia: the COMBAT study. J Card Fail 16(4):293–300. https://doi.org/10.1016/j.cardfail.2009.12.008
18. Orlov MV, Gardin JM, Slawsky M, Bess RL, Cohen G, Bailey W, Plumb V, Flathmann H, de Metz K (2010) Biventricular pacing improves cardiac function and prevents further left atrial remodeling in patients with symptomatic atrial fibrillation after atrioventricular node ablation. Am Heart J 159(2):264–270. https://doi.org/10.1016/j.ahj.2009.11.012
19. Albertsen AE, Mortensen PT, Jensen HK, Poulsen SH, Egeblad H, Nielsen JC (2011) Adverse effect of right ventricular pacing prevented by biventricular pacing during long-term follow-up: a randomized comparison. Eur J Echocardiogr 12(10):767–772. https://doi.org/10.1093/ejechocard/jer136
20. Chan JY, Fang F, Zhang Q, Fung JW, Razali O, Azlan H, Lam KH, Chan HC, Yu CM (2011) Biventricular pacing is superior to right ventricular pacing in bradycardia patients with preserved systolic function: 2-year results of the PACE trial. Eur Heart J 32(20):2533–2540. https://doi.org/10.1093/eurheartj/ehr336
21. Yu CM, Fang F, Luo XX, Zhang Q, Azlan H, Razali O (2014) Long-term follow-up results of the pacing to avoid cardiac enlargement (PACE) trial. Eur J Heart Fail 16(9):1016–1025. https://doi.org/10.1002/ejhf.157
22. John Sutton M, Plappert T, Adamson PB, Li P, Christman SA, Chung ES, Curtis AB (2015) Left ventricular reverse remodeling with biventricular versus right ventricular pacing in patients with atrioventricular block and heart failure in the BLOCK HF Trial. Circ Heart Fail 8(3):510–518. https://doi.org/10.1161/CIRCHEARTFAILURE.114.001626
23. Zhang XY, Shan QJ, Su YG, Yan J, Bao ZH, Gu X, Qiu JP, Qin SM, Xu J, Su H, Zhu H, Guo JF, Lu JP, Zou JG, Chen ML, Xu D, Cao KJ (2016) Efficacy of biventricular pacing on preventing heart failure in patients with high degree atrioventricular block (BIVPACE-AVB Trial). Zhonghua Xin Xue Guan Bing Za Zhi 44(4):331–337. https://doi.org/10.3760/cma.j.issn.0253-3758.2016.04.011
24. Thambo JB, Bordachar P, Garrigue S, Lafitte S, Sanders P, Reuter S, Girardot R, Crepin D, Reant P, Roudaut R, Jais P, Haissaguerre M, Clementy J, Jimenez M (2004) Detrimental ventricular remodeling in patients with congenital complete heart block and chronic right ventricular apical pacing. Circulation 110(25):3766–3772. https://doi.org/10.1161/01.cir.0000150336.86033.8d
25. Wilkoff BL, Cook JR, Epstein AE, Greene HL, Hallstrom AP, Hsia H, Kutalek SP, Sharma A (2002) Dual-chamber pacing or ventricular backup pacing in patients with an implantable defibrillator: the Dual Chamber and VVI Implantable Defibrillator (DAVID) Trial. Jama 288(24):3115–3123
26. Gillis AM, Purerfellner H, Israel CW, Sunthorn H, Kacet S, Anelli-Monti M, Tang F, Young M, Boriani G (2006) Reducing unnecessary right ventricular pacing with the managed ventricular pacing mode in patients with sinus node disease and AV block. Pacing Clin Electrophysiol 29(7):697–705. https://doi.org/10.1111/j.1540-8159.2006.00422.x
27. Bristow MR, Saxon LA, Boehmer J, Krueger S, Kass DA, De Marco T, Carson P, DiCarlo L, DeMets D, White BG, DeVries DW, Feldman AM (2004) Cardiac-resynchronization therapy with or without an implantable defibrillator in advanced chronic heart failure. N Engl J Med 350(21):2140–2150. https://doi.org/10.1056/NEJMoa032423
28. Cleland JG, Daubert JC, Erdmann E, Freemantle N, Gras D, Kappenberger L, Tavazzi L (2005) The effect of cardiac resynchronization on morbidity and mortality in heart failure. N Engl J Med 352(15):1539–1549. https://doi.org/10.1056/NEJMoa050496
29. Chatterjee NA, Upadhyay GA, Ellenbogen KA, Hayes DL, Singh JP (2012) Atrioventricular nodal ablation in atrial fibrillation: a meta-analysis of biventricular vs. right ventricular pacing mode. Eur J Heart Fail 14(6):661–667. https://doi.org/10.1093/eurjhf/hfs036