Suchodolski *et al. Cardiovascular Ultrasound* (2025) 23:14
https://doi.org/10.1186/s12947-025-00349-z

Cardiovascular Ultrasound

REVIEW

Open Access

Echocardiographic imaging in patients with conduction system pacing

Alexander Suchodolski[1,2,4*], Ewa Jędrzejczyk-Patej[1], Wiktoria Kowalska[1,2], Michał Mazurek[1], Radosław Lenarczyk[1], Oskar Kowalski[1], Zbigniew Kalarus[1] and Mariola Szulik[1,3]

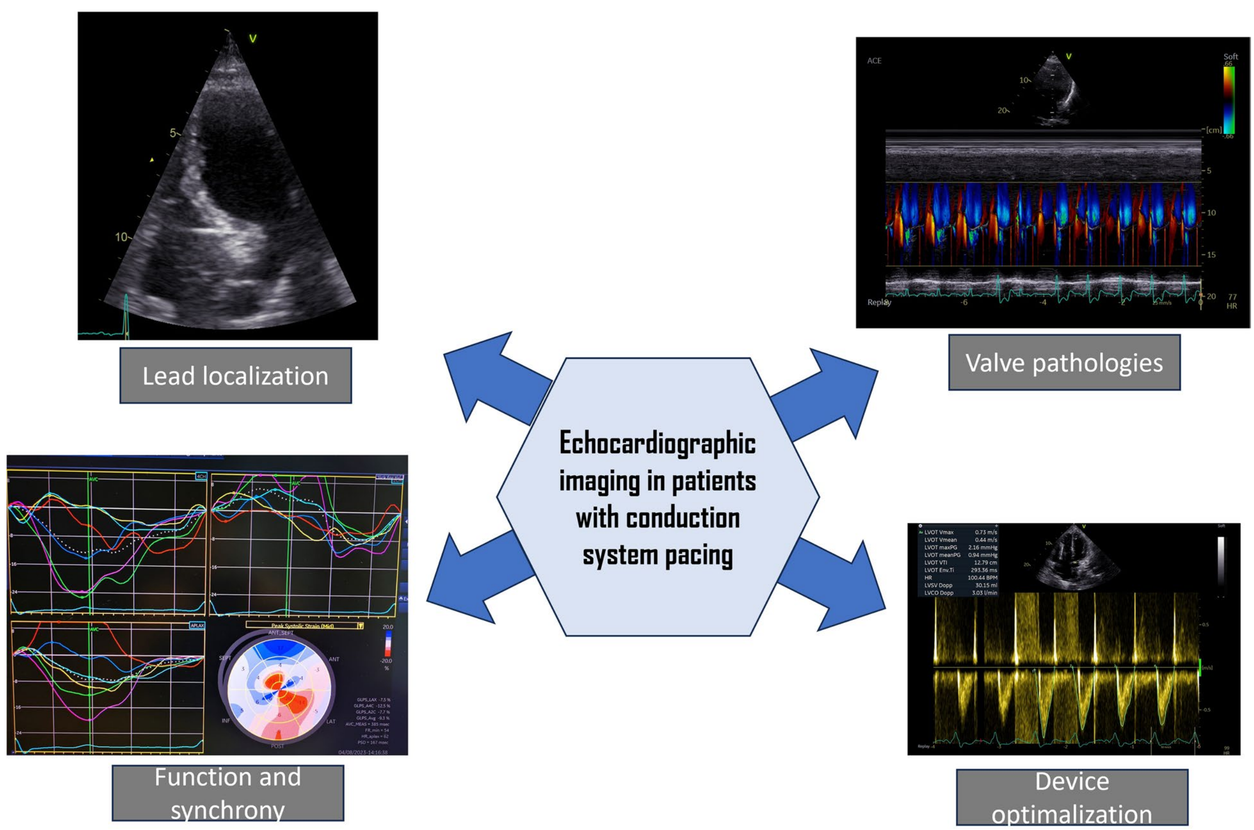
Abstract

Conduction system pacing (CSP), encompassing His-bundle pacing (HBP) and left bundle branch area pacing (LBBAP), revolutionizes cardiac pacing, allowing a more physiological left ventricular activation than conventional right ventricular (RV) pacing through electrode placed in RV apex, interventricular septum or right ventricular outflow tract. Echocardiography plays a pivotal role in patient assessment, primarily by measuring left ventricular ejection fraction (LVEF) to determine the pacing strategy in alignment with current guidelines. Clinical data, simulations and ongoing trials on CSP explore CSP viability across various LVEF conditions. CSP is supposed to defer pacing-induced cardiomyopathy (PiCM) associated with conventional right ventricular pacing (RVP). This paper aims to review the current literature regarding the use of echocardiography in CSP. Images from our experience in the echocardiographic lab were used throughout this document to show our proposals of imaging in CSP. Echocardiography may help to determine lead localization within the interventricular septum (IVS), customizing pacing to individual anatomy and electromechanical indices (like atro-ventricular delay) and evaluates often-overlooked valvular function, a potential PiCM contributor. Three-dimensional (3-D) echocardiography widens the knowledge of lead localization and valvular dysfunction, as well as dyssynchrony assessment. Dyssynchrony, crucial both to resynchronization per se and physiological stimulation is quantified via echocardiography, especially using speckle-tracking imaging. Baseline LVEF and follow-up observation of CSP effects: early in Global Longitudinal Strain (GLS), afterwards in LV volumes and LVEF may improve the future proper qualification of patients. Limited left atrial (LA) and right atrial (RA) strain assessments hold potential in the CSP qualification and response assessment context. Echocardiography complements other imaging modalities for comprehensive patient evaluation. Echocardiography is integral in the CSP clinical use, from patient selection (by showing subtle changes in myocardial function) to post-procedure follow-up (tricuspid regurgitation, LV and RV function, leads and synchrony assessment). GLS, assessed by speckle tracking imaging and profound 2D and 3D (lead placement, septum morphology and global heart function under CSP) analyses show promise in CSP outcome assessment, though standardization is needed.

Keyword Conduction system; Pacing; Echocardiography; Speckle tracking

*Correspondence:
Alexander Suchodolski
alex.suchodolski@gmail.com
Full list of author information is available at the end of the article

Graphical Abstract



Background

Conduction system pacing (CSP) is a novel method of cardiac pacing, which includes His-bundle pacing (HBP) and left bundle branch area pacing (LBBAP). It allows for physiological activation of the left ventricle through the conduction system. [1]

Echocardiography plays an essential role in patient qualification, as left ventricular ejection fraction (LVEF) remains an essential marker for the systolic function assessment. Based on this parameter, clinical decisions regarding the optimal pacing strategy are made as recommended in current guidelines. Patients with LVEF above 40% with presumed pacing rate more than 20% may be considered to His bundle pacing [2] Clinical data and computer simulations show the benefit of this technique over right ventricular apex pacingc(RVAP) [3]. Several trials are outroled to determine the feasibility of CSP in patients with preserved or impaired LVEF. [4]

CSP is hoped to avoid pacing-induced cardiomyopathy (PiCM) caused by "traditional" pacing of the right ventricle (RVP). The definition of PiCM varies; [5] the one proposed in the 2023 HRS/APHRS/LAHRS Guideline on Cardiac Physiologic Pacing for the avoidance and mitigation of heart failure includes:

1. a decline in LVEF of ≥10% with a baseline LVEF ≥50% before RVP,
2. pacing percentage ≥20%, and
3. no alternative explanation for the decline in LVEF following RVP [6].

The mechanism underlying the development of PiCM is not fully understood. Dyssynchrony, caused by non-physiologic pacing of the RV, seems to play a pivotal role. This parameter can be measured and quantified using echocardiographic methods, as demonstrated later in this paper [6].

However, there are more potential roles for echocardiography in the rapidly evolving field of CSP, like lead positioning, and longitudinal strain assessment. This paper aims to review the current literature regarding the use of echocardiography in this field. Images from our experience in the echocardiographic lab were used throughout this document.

Localisation of the lead

In contrast to "classic" pacing, where the electrode is placed in the apex, septum or outflow tract of the RV, in CSP, it is inserted into some part of the interventricular septum (IVS) as determined by electrophysiologic parameters (namely, ECG parameters) to accomplish optimal stimulation. [Fig. 1] Echocardiography allows for anatomical localisation of the pacing lead, after implantation. Using classical acoustic windows, in transthoracic echocardiography, we can determine which part of the interventricular septum the lead is implanted in and which is presumably paced. The first step is to assess whether the lead is located anteriorly or inferiorly, although the clinical implications of this positioning during implantation or follow-up are not yet fully established. We may achieve this using classic transthoracic acoustic windows. If the lead is visible in the four-chamber view (4 CH), this means it is positioned more posteriorly; if it is visualized in the three-chamber view (APLAX)—it is placed more anteriorly in the IVS [Fig. 2].

Similarly, we can track the lead in the left ventricle's parasternal short axis (PSAX) view. Here, we can determine the "height" (from base to apex) of the IVS where the lead is placed. We compare the localisation with the one visible in 4CH and APLAX. The substernal view may also be helpful. More experienced echocardiographers may use modified imaging angles for optimal image quality and more precise lead localisation. Three-dimensional (3-D) imaging modalities (e.g. multislice imaging) may be helpful [Fig. 3].

Besides the implant target point, we can assess echocardiographically at which angle the electrode is inserted into the IVS. Based on this, we can differentiate three situations: the electrode tip located perpendicularly to the IVS or pointing towards either the apex or the base of the heart. Noteworthy in the last case is that the whole electrode has to make a full turn virtually in the RV. The tension caused by this may be a risk factor for future lead displacement. Further research is needed to check the relation between lead localized in the septum on different levels and tricuspid regurgitation.

When localizing the pacing lead, 3-D echocardiography may add an additional benefit. It is currently the method of choice to evaluate the LVEF and, therefore, left ventricular function. This technique can also be used to evaluate valvular dysfunction, which we discussed earlier in this paper.

Another utility of 3-D echocardiography imaging in the context of CSP is the assessment of potential lead perforation through the IVS. In classical 2-D echocardiography, the sonographer may easily misdiagnose the lead piercing into the LV. This can be verified with 3-D modality. However, experiences indicate that assessment of device function is the most feasible and reliable method of inspecting for this potentially dangerous complication. [7]

Although fluoroscopy is routinely used to guide lead placement during device implantation, it has notable limitations, particularly in assessing precise lead location. For instance, a recent Danish registry study on traditional right ventricular pacing (RVP) revealed that up to 20% of leads were unintentionally positioned in the RV free wall, as later confirmed by CT imaging [8]. In the context of conduction system pacing (CSP), fluoroscopic views can be even more challenging due to the proximity of the target areas (e.g., His bundle or left bundle branch) to anatomical landmarks. While no large-scale studies have yet assessed lead misplacement in CSP using advanced imaging, modalities such as CT or echocardiography may be valuable in confirming accurate lead positioning beyond fluoroscopic assessment alone.

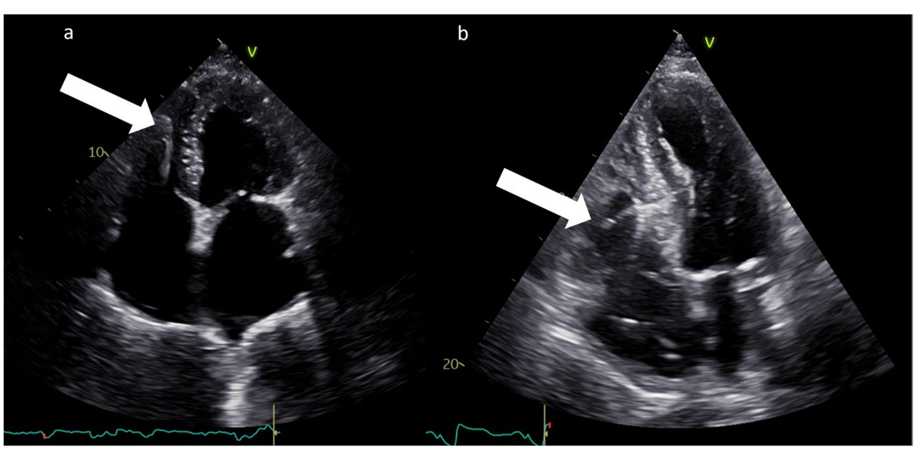


Fig. 1 Conventional lead placement in current right ventricular pacing – apex of right ventricle (**a**—arrow) and conduction system pacing – lead in interventricular septum (**b** – arrow)

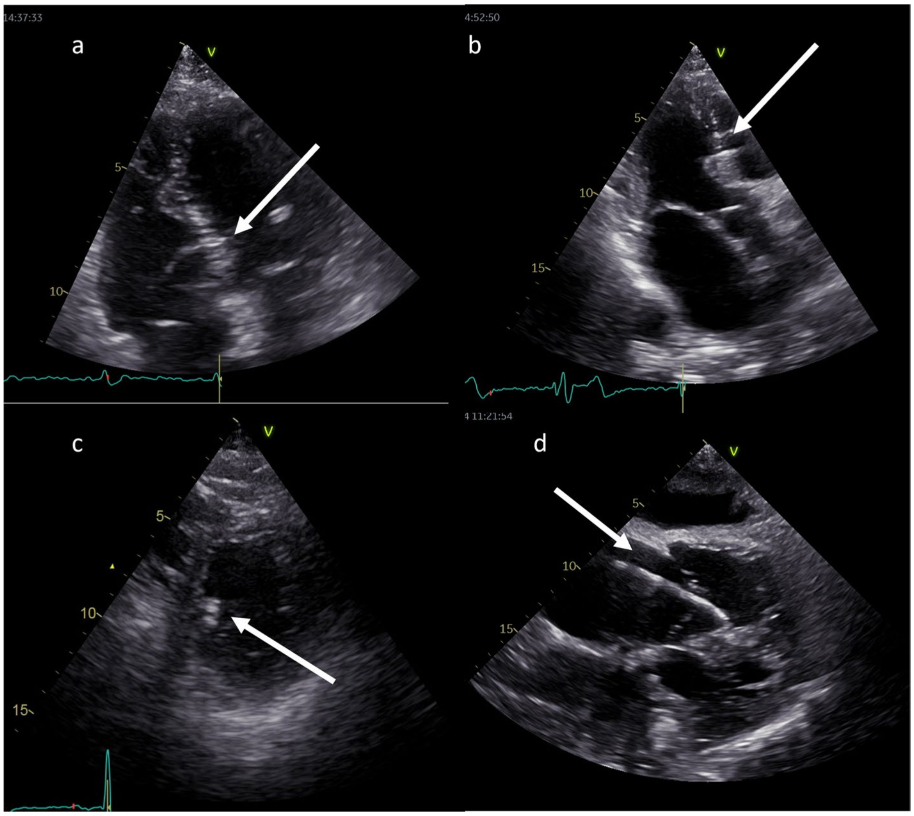


Fig. 2 Evaluation of the conduction system pacing lead placement: posteriorly, if visible in the apical four-chamber view (**a**); more anteriorly in the interventricular septum., if visible in apical long axis view (APLAx) (**b**); in the left ventricle's parasternal short axis—determination of the "height" (from base to apex) in interventricular septum (**c**); the substernal view – insight on the lead and tricuspid valve (**d**)

There is no data about the long-term lead function considering the angle of lead tip implantation into the muscle of septum. It may be deemed that acute angle (looking from the apex) between septum and lead tip may be related to more frequent dislodgement or—due to the wire tension—to more frequent tricuspid regurgitation [Fig. 4].

The potential differences in the clinical course in patients with leads placed in different localisations, as determined by echocardiography, should be controlled in serial echocardiographic studies.

Valvular function

In some cases, classic RV pacing may lead to mitral regurgitation as a result of cardiomyopathy induction (mitral annulus widening, atrial remodelling and fibrillation onset) [9]. In a recent study by Boczar et al. concerning CRT with CSP, mitral regurgitation was graded—only during RVP mitral regurgitation worsened. There is a paucity of original research concerning the long-term effect of CSP on mitral valve function. In some papers, moderate to severe valvular pathologies were even an exclusion criterion [10]. Mitral regurgitation may be one of the factors contributing to the development of PiCM [6].

The incremental beneficial effect of CRT on mitral valve function is well studied and established [11]. CSP seem to have a similar benefit [12] [Fig. 5].

Valve assessment techniques can also be helpful in CSP implantation. The Doppler trace of sufficient mitral regurgitation may be used to assess dP/dtmax. A recent review shows that this hemodynamic response parameter may be used to optimize device implantation [13]

On the other hand, CSP lead implantation may have a detrimental effect on the tricuspid valve apparatus, causing tricuspid regurgitation, as the lead course may cause tension on valve leaflets [Fig. 4]. A more acute angulation of the lead implanted closer to the TV annulus should, therefore, be a risk factor. This pathomechanism seems to be confirmed by a recently published study, where a distance between the lead-implanted site and the tricuspid valve annulus of ≤ 16.1 mm was independently associated with TR deterioration after left bundle branch pacing (LBBP) [14]. This distance and lead placement in the commissure can be assessed more clearly using transesophageal echocardiography

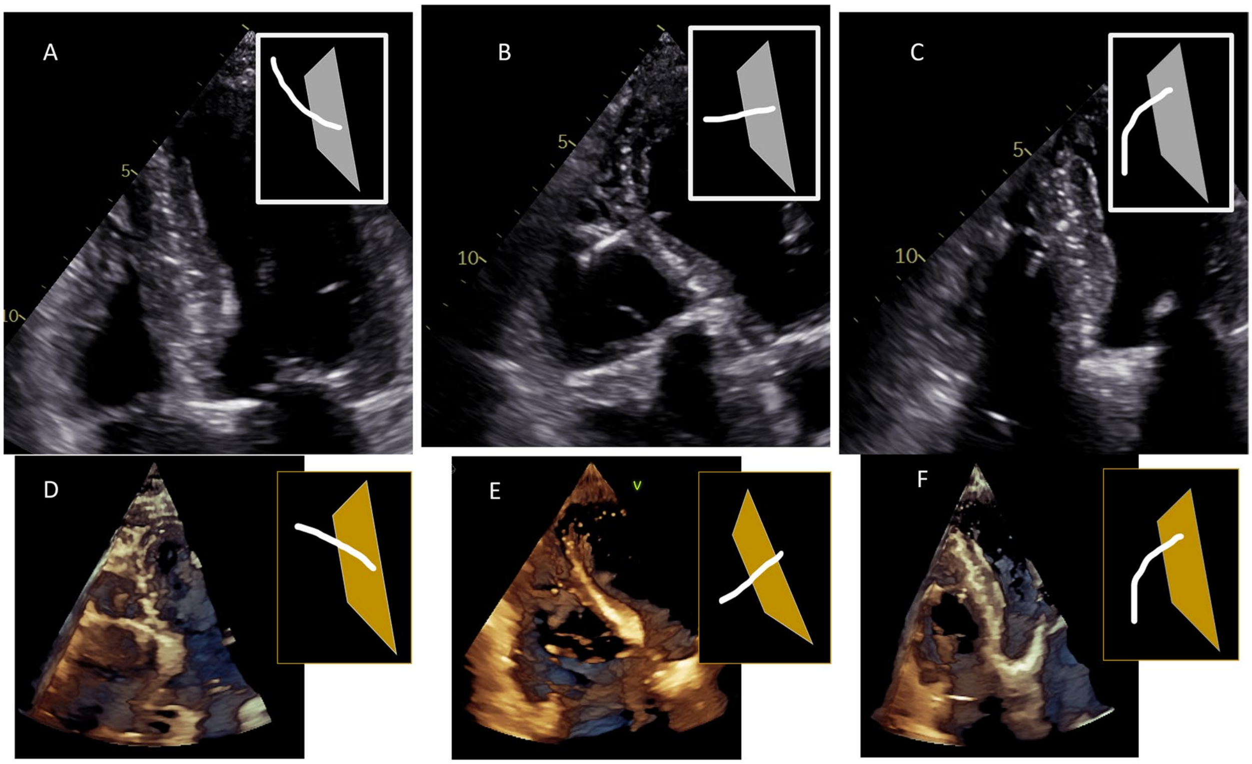


Fig. 3 Evaluation of the conduction system pacing lead placement—three-dimensional imaging modalities—multislice imaging. The lead placement in the interventricular septum is shown on the scheme

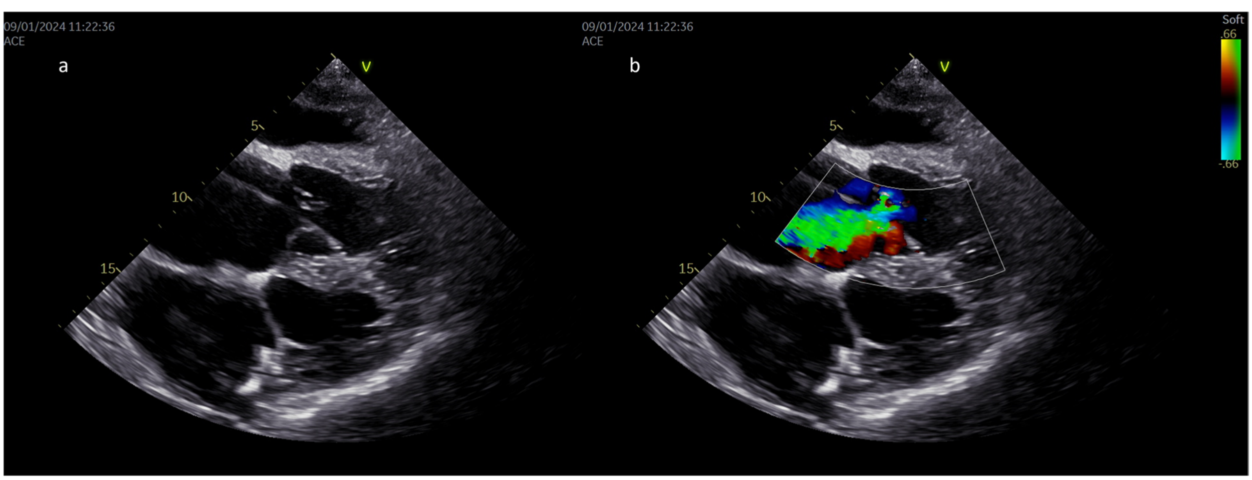


Fig. 4 Tricuspid regurgitation (TR) caused by deflection of the septal tricuspid leaflet by a CSP lead (**a**). TR jet is shown in color Doppler (**b**)

(TEE). TEE performed during implantation may offer precise visualization of the catheter's position relative to the valvular commissures and its potential impact on leaflet motion. It has been demonstrated that TEE-guided placement of the lead in the commissural area, most commonly posteroseptal, was achievable in 95.2% of cases without worsening tricuspid regurgitation. Furthermore, in the group of patients who underwent TEE during the procedure, no deterioration of TR was observed at discharge when compared to baseline. To further assess lead stability, a subset of these patients also underwent 3D transthoracic echocardiography (TTE) in addition to standard TTE at discharge. In all examined individuals, the lead remained in the same position as during the procedure, with no displacement observed during respiratory cycles or with changes in

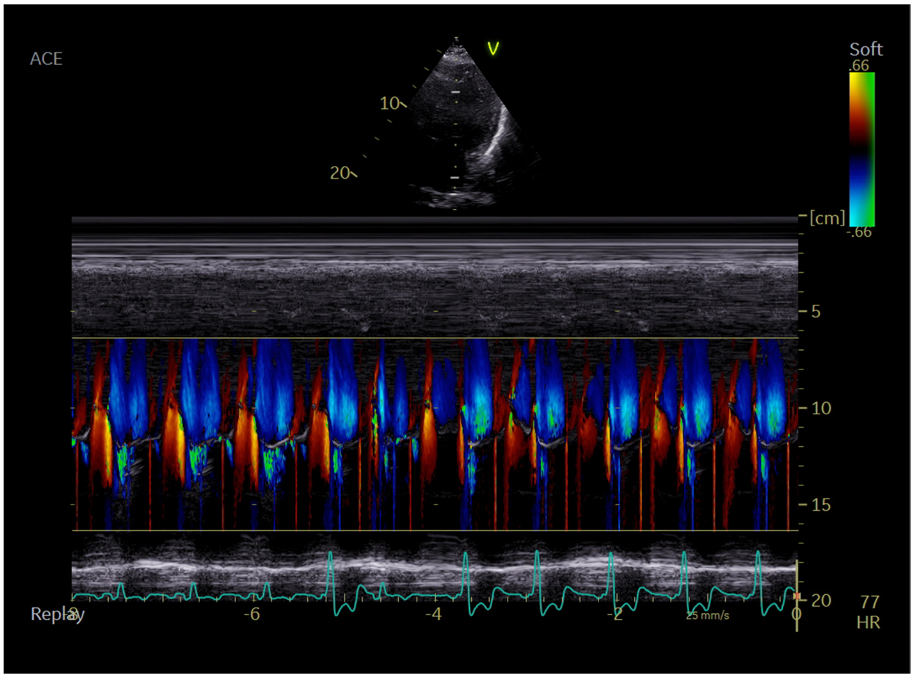


Fig. 5 Change in mitral regurgitation severity during pacing mode shift visualized using M-mode and color Doppler

body posture, indicating short-term mechanical stability of the lead. However, it is worth noting that this study was not conducted exclusively in a CSP patient population [15]. Cases of lead entanglement in chordae tendineae were also described [16].

Dyssynchrony assessment

Dyssynchrony assessment

The main point of the novel CSP method is to establish a more physiologic, synchronized stimulation of both ventricles compared to traditional pacing sites. This should allow us to avoid pathologic changes—first in function and later in the morphology of the heart—thereby preventing PiCM. Therefore, dyssynchrony assessment seems crucial regarding CSP and pacing in general. Besides ECG markers, echocardiography provides a variety of parameters to determine the interplay between RV and LV. Nowadays, strain imaging is becoming increasingly important in this field. One parameter to measure dyssynchrony is peak systolic dispersion (PSD). It is a parameter derived from systolic time intervals that describes the standard deviation of periods to peak systolic segments from all 16 LV segments.

PSD plays an important role in evaluating the coordination and synchronization of myocardial movement and provides a more accurate and sensitive index of early LV systolic function. Beyond being a quantitative marker of mechanical dyssynchrony, it has also been used as an early indicator of LV dysfunction in various clinical contexts—for example, in diabetes mellitus—suggesting its potential utility in the early detection of LV deterioration [17]. Similar insights may emerge in the CSP population. However, at this point, we still lack consistent and robust data. In the studies analyzed so far, results differ—likely, as we discuss in this paper, due to heterogeneity in study designs, patient populations, and follow-up durations.

Chen et al. reported no significant difference in PSD between LBBP, LBFP, and LVSP in patients with QRS <120 ms and EF $\geq 50\%$ [18]. Conversely, Pujol-López et al. [19] showed a decrease in PSD in CSP compared to BiVP. Dell'Era also demonstrated a reduction in PSD in LBBAP patients, while Liu reported a greater improvement in PSD in the LBBAP group than in the BiVP group. On the other hand, Michalik et al. found no significant difference in PSD between HBP and RVP after 6 months of follow-up. These inconsistencies highlight the need for longer-term studies to clarify the role of PSD in assessing mechanical synchrony and predicting outcomes in CSP recipients [20–22].

Strain imaging

Speckle tracking echocardiography (STE) allows for a more precise and repeatable quantification of each heart muscle region's function. Global longitudinal strain (GLS), which can be measured using this method, is a prognostic marker in cardiac resynchronisation therapy [23]. Pre-implant LV GLS appeared to be of prognostic value for future LVEF improvement both in CSP and biventricular pacing. Cut-off value of −7.1% discriminated LVEF responders [19].

STE is a robust and repeatable method for assessing myocardial synchrony. Therefore, repeated analysis by the bedside during pacemaker interrogation may allow for a more precise individualized setting of parameters, allowing for optimal pacing [10]. Echocardiographic follow-up of patients with systolic heart failure (HF) after CSP within 3–12 months is a class I recommendation according to current guidelines [6].

CSP device optimization

Optimization of CSP comes from the algorithms of CRT ultrasound optimization. LV atrio—ventricular dyssynchrony is of concern. CSP optimization elements are as follows (based on CRT criteria): atrioventricular (AV) dyssynchrony—diastolic filling time in relation to RR cycle should be more than 40% The optimization itself is based on AV delay shortening or prolongation in the device setting. Based on the E/A wave profile we can conclude, which way to go:

- if AV delay is prolonged—E and A wave are fused, diastolic filling is shortened and late diastolic mitral regurgitation may occur; AV delay should be shortened,

- if AV delay is reduced—A wave is truncated, LV filling is interrupted by mitral valve closure and thus not completed; AV delay should be prolonged.

The optimization of CSP devices focuses on AV the conduction disturbances—namely PR prolongation. It reveals the fusion of E and A wave: suboptimal filling with the early filling wave interrupted by atrial filling wave. In CSP optimization attention should be paid on AV delay shortening [19].

If needed the optimization of interventricular (V-V) delay (in LOT-CRT devices) should be performed, especially if bundle branch block was observed prior to device implantation [Fig. 6].

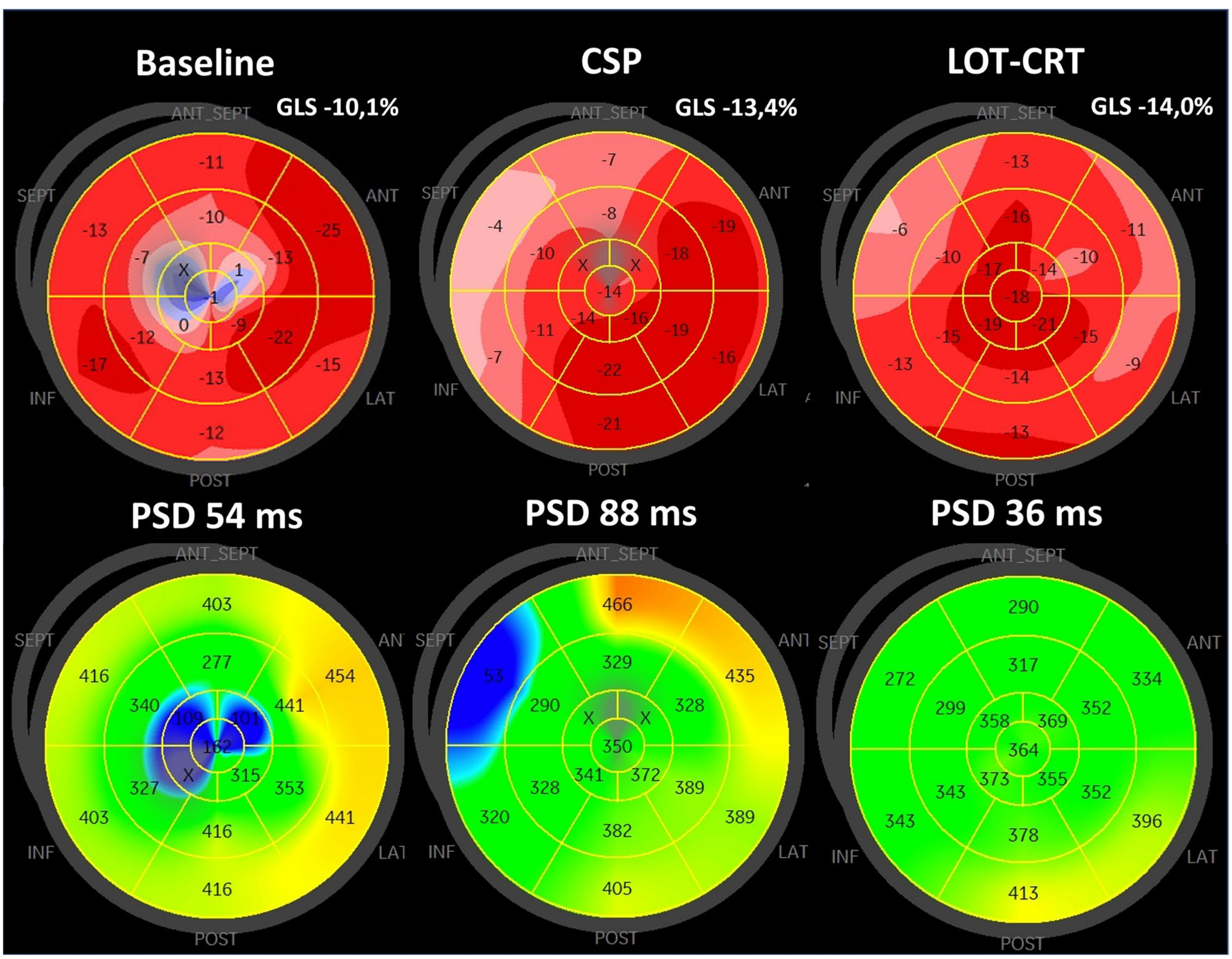


Fig. 6 Longitudinal strain and time to peak strain "bulls eye" plots for baseline, CSP and LOT-CRT (left bundle branch-optimized cardiac resynchronization therapy) in the same patient. In the strain bull's eye and myocardial work analysis, the red areas represent regions with normal longitudinal strain, while the pink areas indicate regions with impaired longitudinal strain. For myocardial work, blue values indicate the shortest times to maximum deformation, red values indicate the longest times, and green values represent normal times

The clinical concern is, that after every AV of VV delay change, AV and VV dyssynchrony the AV and VV dyssynchrony parameters should be checked again and matched (iterative method). It may be time consuming. However—until now, the CSP device setting is focused on the short AV delay.

It was proved that electrophysiology-guided sensed atrioventricular delay programming is concordant with echocardiography based (LV filling profile) iterative method in 71.8% of 71 pts group with CSP devices [24].

Chamber quantification

LV

As changes in GLS are a much more sensitive marker for the deterioration of LV function, STE has been used to compare RVP and CSP. In a study by Wen et al., no difference between these two groups (in terms of global strain) after 6 months has been shown [25]. Similarly, a study by Sun et al. showed no difference between systolic strain at baseline and after pacemaker implantation, comparing RVP and LBBP groups. Notably, the measurements were taken right after implantation. [26]. In the study with one of the longest follow-ups (18 months) with GLS measurements comparing LBBP and RVSP—GLS was significantly higher in the CSP group. This effect, nevertheless, became visible after 6 months and peaked at 12 months (with a slow rise till 18 months) [27]. Michalik et al. showed no increase in GLS after six months in the HBP group, but also no decrease as measured in the RVP arm [20]. Longer follow-up (at least 6 months) periods are necessary to determine the differences in myocardial strain. Changes in GLS may be linked to the baseline values of LVEF, as shown in research by Bednarek et al. in patients with LBBAP. GLS and LVEF improved in patients with an LVEF < 50% while remaining constant in patients with an LVEF > 50% at baseline [28]. Myocardial strain changes may take months or years to manifest, particularly with CSP, where remodeling is often subtler. Thus, longer follow-up periods and larger studies are needed to validate these trends.

LA

In a recent study by Liu et al., comparing RVAP with LBBP left atrial strain was analyzed, however, no significant differences between the two groups were found. [Liu 2021] Neither in a study population of patients with HOT-CRT (combined pacing: lead on LV via coronary sinus and LBBP) between different stimulation modes [10]. Further studies with longer follow-up are needed (as in LV myocardial function). Deterioration of LA function was a part of the pathomechanism of PICM [9]

RV

The primary goal of CSP is to achieve interventricular synchrony. The echocardiographic assessment of the free wall of the right ventricle seems to be a necessary step. No difference in RV GLS between baseline and after 3 months of LBBAP was measured by Dell'Era and his team [21]. Tian et al. divided the study group into normal and abnormal RV function subgroups (based on 3-D RV ejection fraction—3-D RVEF). It was confirmed that in the 6 months of follow-up RV dyssynchrony improved in both groups, but RVEF only in the previously RV dysfunctional group [29]. Other researchers found a reduction of this parameter regardless of whether"traditional"or CSP was used [30].

RA

Strain assessment of the right atrium (RA) is a novel imaging approach and, to our knowledge, has not been used yet in the setting of CSP.

In Table 1 we summarized the current medical literature concerning speckle tracking parameters in CSP.

Conclusion

Echocardiography in the context of pacemaker implantation and pacing may add a valuable tool for the assessment of: lead localization, dyssynchrony, chamber and valvular function.

Strain imaging seems to be the method of choice to evaluate and quantify myocardial function under the CSP in different patient populations.

It seems that shortly after CSP implantation both GLS and LVEF increase. After 6 months, in most studies, this effect is maintained, or no significant differences in LVEF and GLS are found between classical pacing and CSP. However, long-term follow-up (18 months) confirms a beneficial effect on both LVEF and GLS in the subgroup of patients who had reduced LVEF (< 50%) prior to CSP implantation. The literature, so far sparse, regarding echocardiographic parameters in the context of CSP is incoherent, as the effects on LVEF and GLS vary. In some studies, there is no difference compared to "traditional" pacing modes, while in others, a decrease of these parameters is observed in the latter. Comparison between different studies is difficult due to dissimilarities in inclusion and exclusion criteria, as well as varying follow-up periods. Making assumptions about the underlying mechanisms of these findings is demanding. Another important aspect is the fact that CSP includes a variety of pacing sites and modes, so a detailed evaluation of the mechanical effects of the septal lead position and stimulation has to take this into account. Some reports also suggest that CSP may help avoid PICM. However, longer

Table 1 Echocardiographic Findings Following Conduction System Pacing Across Published Studies

First author	Year	Pacing types	No of patients	Non-echocardiographic parameter	Follow-up after proce dure	LVEF	GLS	Dyssynchronyand different chocardiographic parameters
Cheng [31]	2024	LBBP, LBFP and LVSP QRS < 120 and EF ≥ 50%	56 (18, 16, 22 respectively)	QRS, LVAT	6 months	EF ≥ 50% (average above 60%)—no significant changes in follow-up	no changes between the groups in the follow-up	GCS, GRS PSD—no differences between the groups; lead tip depth in the septum and lead tip distance from the tricuspid annulus and apex
Pujol-López [23]	2024	CSP vs BiVP ON and OFF programming	70		6 and 12 months	increased in both groups	- improved in both groups	In both groups: PSD decrease LVESV decrease Septal flash disappearance septal rebound disappearance LBBB strain pattern disappearance
Tian [29]	2024	LBBAP	65	NT-proBNP, QRS,	6 months	increased	for RV and LV improved	LVEF RV and LV GLS LVEDD decrease LVESD decrease significant MR decrease 3D RVEF LV and RV dyssynchrony decrease
Boczar [10]	2023	CRT (BiVP) + HBP	21	QRS	1–2 days	Increased	Improved	LVEDD LVESD LVSV MR grade LA strain
Bednarek [28]	2023	LBBAP	151	QRS, NTproBNP	Median 23 months, min 1 month	Increased if LVEF < 50%	improved if LVEF < 50%	LA strain
Dell'Era [21]	2023	LBBAP	56	QRS	Implantation, < 24 h and 3 months	Increased	worsened	PSD decrease IVMD decrease
Michalik [20]	2021	HBP vs RVP	50	QRS	1 day, 6 months	Not measured	Stable	RVP PSD and LAVI increased HBP PSD and LAVI decreased

Table 1 (continued)

First author	Year	Pacing types	No of patients	Non-echocardiographic parameter	Follow-up after proce dure	LVEF	GLS	Dyssynchronyand different chocardiographic parameters
Sun [26]	2020	LBBP vs RVP	32		Before and after implant	No difference	No difference	2D-TD PSS (18 segments) and 2D-SD PSS (18 segments) shorter under LBBP than under RVP
Tang [32]	2019	HBP vs RVAP	62		1, 3 and 6 months	Not measured	Not measured	3D-TD 3D-SD
Mei [33]	2023	LBBAP, RVSP, RVAP	90	NTproBNP, QRS	before and 4 weeks	no changes	GLS best in LBBAP, worst in RVAP	GLS SDI—the shortest in LBBAP Longitudinal and circumferential Tε-dif—the shortest in LBBAP (3D) TMSV 16-SD—the shortest in LBBAP
Wen [25]	2021	LBBP vs RVSP	65		before and 6 months	No difference	No difference	
Yao [27]	2022	RVSP vs LBBP	50		before, 6, 12 and 18 months	Not measured	Higher	GRS GCS
Zhao [22]	2022	LBBAP with or without RBBB	40		1 month	No difference	No difference	LAd LAVi RAd LVEDd LVESV LVEDV LVEF RVFAC TAPSE TV-s' TMAD Dyssynchrony measured as difference in peak displacement or systolic time to peak velocity of mitral and tricuspid annuli—shorter in non-RBBB group

Table 1 (continued)

First author	Year	Pacing types	No of patients	Non-echocardiographic parameter	Follow-up after proce dure	LVEF	GLS	Dyssynchronyand different chocardiographic parameters
Liu [34]	2021	RVOP vs LBBP	84	BNP, QRS duration, interval, amplitude	Before, 7 days	No difference	Not measured	LAd e' E wave A wave E/A E/e' LAEF LVEF VTI LA strain
Xie [35]	2021	RVAP, RVOP, HBP, LBBP	21		acute changes	Stable	Stable in LBBP	Yu index—shorter in LBBP than RVAP PSD—significantly increased in RVAP, shorter in LBBP than RVAP LVEF IVMD—significantly increased in RVAP LVEDD LVEDV LVESD TAPSE
Liu [36]	2021	CRT vs LBBP	62	QRS	3 and 6 months after implantation			IVMD, PSD—greater improvement in LBBAP than BVP
Mirolo [37]	2023	LBBAP	134 (47 LBBB; 38 RBBB, the rest—narrow QRS)	QRS duration, the QRS axis, V6 RWPT, the R/Q ratio in V1	X	Not measured	Not measured	IVMD—decrease in LBBB and RBBB group LVMDT—decrease only in LBBB group

In the table were only indicated values and differences that are statistically significant

3D-SD Three-Dimensional Speckle Tracking, *3D-TD* Three-Dimensional Tissue Doppler, *BiVP* Biventricular pacing; *BNP* B-type natriuretic peptide, *CRT* Cardiac Resynchronization Therapy, *CSP* Conduction System Pacing, *GCS* Global Circumferential Strain, *GLS* Global Longitudinal Strain, *GLPS* Global Longitudinal Peak Strain, *GRS* Global Radial Strain, *HBP* His Bundle Pacing, *IVMD* Interventricular Mechanical Delay, *LAEF* Left atrial ejection fraction, *LBBAP* Left Bundle Branch Area Pacing, *LBBP* Left Bundle Branch Pacing, *Tε-dif* absolute max difference of time to peak strain; *LVAT* Left venctricular activation time, *LVEDD* Left Ventricular End-Diastolic Diameter, *LVEDV* Left Ventricular End-Diastolic Volume, *LVEF* Left Ventricular Ejection Fraction, *LVMDT* mean of the three dispersion times (from the first to the latest) assessed in each of the three views *LVS* Left Ventricular Stroke Volume, *MR* Mitral Regurgitation, *NTproBNP* N-terminal pro B-type natriuretic peptide, *PSD* Peak systolic dispersion, *RVP* Right Ventricular Pacing, *RAd* Right Atrial Diameter, *RVAP* Right Ventricular Apical Pacing, *RVFAC* Right Ventricular Fractional Area Change, *RVOP* Right Ventricular Outflow Pacing, *RVSP* Right Ventricular Septal Pacing, *SDI* Systolic dyssynchrony index, *TAPSE* Tricuspid Annular Plane Systolic Excursion, *TDI* Tissue Doppler Imaging, *TMAD* Tissue Mitral Annular Displacement, *TMSV 16-SD (R-R%)* standard deviation of time from the QRS starting point to the minimum systolic volume of 16 LV segments, *TV-s'* Tricuspid Valve S'Wave, *VTI* Velocity time integral follow-up periods are needed, as the deteriorating effect of pacing on ventricular function may present itself later on. Furthermore, LBBAP appears to have no effect on the severity of mitral regurgitation [10]. Regarding QRS width – it is deemed that LBBAP in routine practice preserves synchrony in patients with narrow and RBBB QRS and reduces dyssynchrony in patients with LBBB [37]

Echocardiography is not only crucial in preprocedural screening and selection of patients, but it also allows optimization of device programming and follow-up of patients. Future progress in the field of CSP will be accompanied by novel findings in the field of echocardiography, allowing for optimal patient treatment and improved long-term outcomes.

Limitations

The current literature demonstrates a lack of consistency among studies evaluating CSP, with some reporting clinical benefits while others show no significant advantage over conventional pacing. This variability in evidence underscores the need for further research to clarify the long-term efficacy of conduction system pacing.

Abbreviations

CSP	Conduction System Pacing
HBP	His-Bundle Pacing
LBBAP	Left Bundle Branch Area Pacing
RV	Right Ventricle / Right Ventricular
LVEF	Left Ventricular Ejection Fraction
PiCM	Pacing-Induced Cardiomyopathy
RVP	Right Ventricular Pacing
GLS	Global Longitudinal Strain
LA	Left Atrium / Left Atrial
RA	Right Atrium / Right Atrial
4 CH	Four-Chamber View
APLAX	Apical Long-Axis View
PSAX	Parasternal Short-Axis View
IVS	Interventricular Septum
TV	Tricuspid Valve
CRT	Cardiac Resynchronization Therapy
ECG	Electrocardiogram
STE	Speckle Tracking Echocardiography
PSD	Peak Systolic Dispersion
LV	Left Ventricle / Left Ventricular
LBBB	Left Bundle Branch Block
RVEF	Right Ventricular Ejection Fraction
LAVI	Left Atrial Volume Index
NT-proBNP	N-terminal pro B-type Natriuretic Peptide
2-D	Two-Dimensional
3-D	Three-Dimensional
RVAP	Right Ventricular Apex Pacing
LVEDD	Left Ventricular End-Diastolic Diameter
LVESD	Left Ventricular End-Systolic Diameter
LVSV	Left Ventricular Stroke Volume
MR	Mitral Regurgitation
dP/dtmax	Maximum Rate of Pressure Change
AV	Atrioventricular
VV	Interventricular
E/A wave	Early Diastolic Filling Wave / Atrial Contraction Wave
LOT	Left bundle branch area pacing Optimized Therapy
RVSP	Right Ventricular Septal Pacing
SDI	Systolic Dyssynchrony Index
TMSV	Time to Minimum Systolic Volume
Tε-dif	Time Strain Difference

Acknowledgements
Not applicable.

Conflict of interest
The authors declare that they have no conflicts of interest relevant to the content of this manuscript.

Authors' contributions
A.S. (Alexander Suchodolski) and M.S. (Mariola Szulik) made significant contributions to this study. Specifically, A.S. and M.S. conceptualized the study, designed the research methodology, and conducted the majority of the research work. E.J.P. (Ewa Jędrzejczyk-Patej), W.K. (Wiktoria Kowalska), and M.M. (Michał Mazurek) contributed to data collection and preliminary analysis. R.L. (Radosław Lenarczyk), O.K. (Oskar Kowalski), and Z.K. (Zbigniew Kalarus) provided additional support with data interpretation and manuscript review. A.S. and M.S. wrote the main manuscript text and prepared all figures. E.J.P., W.K., and M.M. assisted in drafting specific sections. All authors reviewed and approved the final manuscript.

Funding
Co-funded by the Metropolis of Upper Silesia and Zagłębie as part of the "Metropolitan Science Support Fund" program

Data availability
No datasets were generated or analysed during the current study.

Ethics approval and consent to participate
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Cardiology and Electrotherapy, Faculty of Medical Sciences, Silesian Center for Heart Diseases, Medical University of Silesia, ZabrzeKatowice, Poland. [2]Doctoral School of the, Medical University of Silesia, Katowice, Katowice, Poland. [3]Collegium Medicum - Faculty of Medicine, Department of Medical and Health Sciences, Faculty of Applied Sciences, WSB University, Dąbrowa Górnicza, Poland. [4]Silesian Center for Heart Diseases, Marii Skłodowskiej-Curie 9, 41-800 Zabrze, Poland.

Received: 6 January 2025 Accepted: 30 April 2025
Published online: 17 May 2025

References

1. Burri H, Jastrzebski M, Cano Ó, et al. EHRA clinical consensus statement on conduction system pacing implantation: endorsed by the Asia Pacific Heart Rhythm Society (APHRS), Canadian Heart Rhythm Society (CHRS), and Latin American Heart Rhythm Society (LAHRS). EP Eur. 2023;25(4):1208–36. https://doi.org/10.1093/EUROPACE/EUAD043.
2. Glikson M, Nielsen JC, Kronborg MB, et al. 2021 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy. Eur Heart J. 2021;42(35):3427–520. https://doi.org/10.1093/eurheartj/ehab364.
3. Meiburg R, Rijks JHJ, Beela AS, et al. Comparison of novel ventricular pacing strategies using an electro-mechanical simulation platform. Europace. 2023;25:1–11. https://doi.org/10.1093/europace/euad144.
4. Vijayaraman P, Chelu MG, Curila K, et al. Cardiac Conduction System Pacing: A Comprehensive Update. *JACC Clin Electrophysiol*. Published online August 2023. https://doi.org/10.1016/J.JACEP.2023.06.005
5. Naqvi TZ, Chao CJ. Adverse effects of right ventricular pacing on cardiac function: prevalence, prevention and treatment with physiologic pacing. Trends Cardiovasc Med. 2023;33(2):109–22. https://doi.org/10.1016/J.TCM.2021.10.013.
6. Chung MK, Patton KK, Lau C-P, et al. 2023 HRS/APHRS/LAHRS guideline on cardiac physiologic pacing for the avoidance and mitigation of heart failure. Hear Rhythm. 2023;20(9):e17–91. https://doi.org/10.1016/J.HRTHM.2023.03.1538.
7. Akbarzadeh MA, Mollazadeh R, Sefidbakht S, Shahrzad S, Bahrololoumi Bafruee N. Identification and management of right ventricular

perforation using pacemaker and cardioverter-defibrillator leads: A case series and mini review. Journal of Arrhythmia. 2017;33(1):1. https://doi.org/10.1016/J.JOA.2016.05.005.
8. Fruelund PZ, Sommer A, Frøkjær JB, Lundbye-Christensen S, Zaremba T, Søgaard P, Graff C, Vraa S, Mahalingasivam AA, Thøgersen AM, Pedersen MR, Riahi S. Risk of Pacing-Induced Cardiomyopathy in Patients with High-Degree Atrioventricular Block—Impact of Right Ventricular Lead Position Confirmed by Computed Tomography. Journal of Clinical Medicine. 2022;11(23):7228. https://doi.org/10.3390/jcm112372288.
9. Ponnusamy SS, Syed T, Vijayaraman P. Pacing induced cardiomyopathy: recognition and management. Heart. Published online 2023:1–9. https://doi.org/10.1136/heartjnl-2022-321723
10. Sun Z, Di B, Gao H, Lan D, Peng H. Assessment of ventricular mechanical synchronization after left bundle branch pacing using 2-D speckle tracking echocardiography. Clin Cardiol. 2020;43(12):1562–72. https://doi.org/10.1002/CLC.23481.
11. Russo E, Russo G, Cassese M, Braccio M, Carella M, Compagnucci P, Dello Russo A, Casella M. The Role of Cardiac Resynchronization Therapy for the Management of Functional Mitral Regurgitation. Cells. 2022;11(15):2407. https://doi.org/10.3390/CELLS1115240711.
12. Pujol-López M, Jiménez Arjona R, Guasch E, Borràs R, Doltra A, Vázquez-Calvo S, Roca-Luque I, Garre P, Ferró E, Niebla M, Carro E, Puente JL, Uribe L, Invers E, Castel MÁ, Arbelo E, Sitges M, Mont L, Tolosana JM. Conduction system pacing vs. biventricular pacing in patients with ventricular dysfunction and AV block. Pacing Clin Electrophysiol. 2022;45(9):1115–1123. https://doi.org/10.1111/pace.14535. Epub 2022 Jun 1. PMID: 35583311; PMCID: PMC9796875.
13. Elliott MK, Strocchi M, Sieniewicz BJ, Sidhu B, Mehta V, Wijesuriya N, Behar JM, Thorpe A, Martic D, Wong T, Niederer S, Rinaldi CA. Biventricular endocardial pacing and left bundle branch area pacing for cardiac resynchronization: Mechanistic insights from electrocardiographic imaging, acute hemodynamic response, and magnetic resonance imaging. Heart Rhythm. 2023F;20(2):207–16. https://doi.org/10.1016/j.hrthm.2022.10.019. Epub 2022 Oct 28 PMID: 36575808.
14. Hu Q, You H, Chen K, Dai Y, Lu W, Li Y, Cheng C, Zhou Y, Wang J, Chen R, Zhang S. Distance between the lead-implanted site and tricuspid valve annulus in patients with left bundle branch pacing: Effects on postoperative tricuspid regurgitation deterioration. Heart Rhythm. 2023;20(2):217–23. https://doi.org/10.1016/J.HRTHM.2022.10.027.
15. Gmeiner J, Sadoni S, Orban M, Fichtner S, Estner H, Massberg S, Hagl C, Näbauer M, Hausleiter J, Braun D. Prevention of Pacemaker Lead-Induced Tricuspid Regurgitation by Transesophageal Echocardiography Guided Implantation. JACC Cardiovasc Interv. 2021D 13;14(23):2636–8. https://doi.org/10.1016/j.jcin.2021.08.042. PMID: 34887055.
16. Chhetri, C., Haseeb, S., Ansari, U. A., & Goyal, R. (2023). Abstract 16739: Tricuspid Regurgitation Following Conduction System Pacing Lead Entanglement in Chordae Tendineae. Circulation, 148(Suppl_1). https://doi.org/10.1161/CIRC.148.SUPPL_1.16739
17. Li C, Yuan M, Li K, et al. Value of peak strain dispersion in discovering left ventricular dysfunction in diabetes mellitus. Sci Rep. 2020;10:21437. https://doi.org/10.1038/s41598-020-78621-7.
18. Chen Z, Zhou X, Ma X, Chen K. Recruitment of the cardiac conduction system for optimal resynchronization therapy in failing heart. Front Physiol. 2022;13:1045740. https://doi.org/10.3389/FPHYS.2022.1045740/BIBTEX.
19. Pujol-López M, Jiménez-Arjona R, Garcia-Ribas C, Borràs R, Guasch E, Regany-Closa M, Graterol MR, Niebla M, Carro E, Roca-Luque I, Guichard JB, Castel MA, Arbelo E, Porta-Sánchez A, Brugada J, Sitges M, Tolosana JM, Doltra A, Mont L. Longitudinal comparison of dyssynchrony correction and 'strain' improvement by conduction system pacing: LEVEL-AT trial secondary findings. European Heart Journal - Cardiovascular Imaging. 2024;25:1394–404. https://doi.org/10.1093/ehjci/jeae132.
20. Yao L, Qi Y, Xiao S, Liu R, Wo J. Effect of left bundle branch pacing on left ventricular systolic function and synchronization in patients with third-degree atrioventricular block, assessment by 3- dimensional speckle tracking echocardiography. J Electrocardiol. 2022;72:61–5. https://doi.org/10.1016/J.JELECTROCARD.2022.02.013.
21. Bednarek A, Kiełbasa G, Moskal P, et al. Left bundle branch area pacing prevents pacing induced cardiomyopathy in long-term observation. Pacing Clin Electrophysiol. 2023;46(7). https://doi.org/10.1111/PACE.14707
22. Zhao R, Xiong F, Deng X, Wang S, Liu C, Xu M, Tan K, Wang X. Early assessment of ventricular synchronization and function after left bundle-branch-area pacing with right bundle-branch block. BMC Cardiovasc Disord. 2022A 21;22(1):380. https://doi.org/10.1186/s12872-022-02818-z. PMID:35989329;PMCID:PMC9394046.
23. Appadurai V, D'Elia N, Mew T, et al. Global longitudinal strain as a prognostic marker in cardiac resynchronisation therapy: A systematic review. Int J Cardiol Hear Vasc. 2021;35. https://doi.org/10.1016/J.IJCHA.2021.100849
24. Kaza N, Keene D, Vijayaraman P, Whinnett Z. Frontiers in conduction system pacing: treatment of long PR in patients with heart failure. Eur Heart J Suppl. 2023Nov 9;25(Suppl G):G27–32. https://doi.org/10.1093/eurheartjsupp/suad116.PMID:37970515;PMCID:PMC10637839.
25. Coluccia G, Dell'Era G, Ghiglieno Ch, De Vecch F, Spinoni E, Santagostino M, Guido A, Zaccaria M, Patti G, Accogli M, Palmisano P. Optimization of the atrioventricular delay in conduction system pacing. J Cardiovasc Electrophysiol. 2023Jun;34(6):1441–51. https://doi.org/10.1111/jce.15927.
26. Wen H, Chen Y, Liang Z. Left ventricular systolic function between left bundle branch pacing and right ventricular septum pacing in patients with pacemaker dependence by three-dimensional speckle tracking imaging. Zhong Nan Da Xue Xue Bao Yi Xue Ban. 2021;46(4):379–84. https://doi.org/10.11817/J.ISSN.1672-7347.2021.200640.
27. Sun Z, Di B, Gao H, Lan D, Peng H. Assessment of ventricular mechanical synchronization after left bundle branch pacing using 2-D speckle tracking echocardiography. Clin Cardiol. 2020 Dec;43(12):1562–1572. https://doi.org/10.1002/clc.23481. Epub 2020 Oct 21. PMID: 33085114; PMCID: PMC7724215.
28. Michalik J, Dabrowska-Kugacka A, Kosmalska K, Moroz R, Kot A, Lewicka E, Szolkiewicz M. Hemodynamic Effects of Permanent His Bundle Pacing Compared to Right Ventricular Pacing Assessed by Two-Dimensional Speckle-Tracking Echocardiography. Int J Environ Res Public Health. 2021N 8;18(21):11721. https://doi.org/10.3390/ijerph182111721.PMID:34770235;PMCID:PMC8583013.
29. Dell'Era G, Ghiglieno C, Degiovanni A, et al. Early effects of left bundle branch area pacing on ventricular activation by speckle tracking echocardiography. J Interv Card Electrophysiol Published online. 2023. https://doi.org/10.1007/S10840-023-01616-7.
30. Tian F, Weng H, Liu A, Liu W, Zhang B, Wang Y, Cheng Y, Cheng S, Fulati Z, Zhou N, Kong D, Pan C, Su Y, Xu N, Chen H, Shu X. Effect of left bundle branch pacing on right ventricular function: 3-dimensional echocardiography study. Heart Rhythm. 2024;21:445–53. https://doi.org/10.1016/j.hrthm.2023.12.012.
31. Cheng Ch, Sun L, Peng X, Wang Y, Shi L Zhao T, Wei Z, Tian Y, Liu X. Difference of ventricular synchrony between LBBP, LBFP and LVSP: A speckle tracking echocardiographic study. Journal of Interventional Cardiac Electrophysiology (2024) 67:539–547. https://doi.org/10.1007/s10840-023-01620-x
32. Tang J, Chen S, Liu L, Liao H, Zhan X, Wu S, Liang Y, Chen O, Lin C, Zhang Q, Wei H, Chen D. Assessment of Permanent Selective His Bundle Pacing in Left Ventricular Synchronization Using 3-D Speckle Tracking Echocardiography. Ultrasound Med Biol. 2019F;45(2):385–94. https://doi.org/10.1016/j.ultrasmedbio.2018.10.006. Epub 2018 Dec 1.
33. Mei Y, Han R, Cheng L, Li R, He Y, Xie J, Wang Z, Wu Y. Assessment of cardiac function and ventricular mechanical synchronization in left bundle branch area pacing by speckle tracking and three-dimensional echocardiography. Am J Cardiol. 2023;187:1–9. https://doi.org/10.1016/j.amjcard.2022.10.012.
34. Liu Q, Yang J, Bolun Z, et al. Comparison of cardiac function between left bundle branch pacing and right ventricular outflow tract septal pacing in the short-term: A registered controlled clinical trial. Int J Cardiol. 2021;322:70–6. https://doi.org/10.1016/j.ijcard.2020.08.048.
35. Xie H, Chen X, Wang Y, Cheng Y, Zhao Y, Liu Y, Liu Y, Ge Z, Chen H, Shu X. Comparison of the Acute Effects of Different Pacing Sites on Cardiac Synchrony and Contraction Using Speckle-Tracking Echocardiography. Front Cardiovasc Med. 2021N;11(8). https://doi.org/10.3389/fcvm.2021.758500.PMID:34859073;PMCID:PMC8631923.
36. Liu W, Hu C, Wang Y, Cheng Y, Zhao Y, Liu Y, Zheng S, Chen H, Shu X. Mechanical Synchrony and Myocardial Work in Heart Failure Patients With

Left Bundle Branch Area Pacing and Comparison With Biventricular Pacing. Front Cardiovasc Med. 2021;20(8):727611.
37. Mirolo A, Chaumont C, Auquier N, Savoure A, Godin B, Vandevelde F, Eltchaninoff H, Anselme F. Left bundle branch area pacing in patients with baseline narrow, left, or right bundle branch block QRS patterns: insights into electrocardiographic and echocardiographic features. Europace. 2023;25(2):526–35. https://doi.org/10.1093/europace/euac223. PMID:36480437;PMCID:PMC9935006.

Publisher's Note