

Clinical Research

Simplified Electrocardiogram Criteria to Guide Conduction System Pacing: Is it Possible to Democratize the Procedure?

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See editorial by Philippon et al., pages 1933-1935 of this issue.

ABSTRACT

Background: Conduction system pacing (CSP) is recommended when high ventricular pacing burden is expected, and as an alternative to cardiac resynchronization. Multiple studies have demonstrated the importance of achieving CSP over deep septal pacing, with associated improved clinical outcomes. There are various currently accepted criteria to ascertain CSP lead placement, which all require an electrophysiology (EP) system. EP systems are not widely available, limiting CSP lead placement to tertiary hospitals and specialized centres. The purpose of this study was to identify electrocardiography (ECG)-only criteria capable of confirming CSP capture and thereby improve accessibility to this pacing strategy.

Methods: We retrospectively extracted all attempted CSP implantations at our centre. Established CSP criteria were assessed for each patient, alongside the presence of ECG-only features.

Results: The presence of 3 ECG-only criteria was found to be highly predictive of CSP in patients without a previously paced rhythm: terminal S wave in V_5 - V_6 ; isoelectric ST segment in V_6 ; and positive T wave in V_5 - V_6 . When applied to patients with unpaced baseline rhythms and a V_6 - V_1 interpeak interval > 44 ms, these criteria demonstrated a predictive accuracy of 80.4%, with a sensitivity of 87.8% and a specificity of 76.5%.

Conclusions: The findings suggest that CSP capture may be reliably identified using a combination of simple ECG-based markers in patients without prior ventricular pacing. Implementation of these criteria may facilitate broader adoption of CSP by enabling reliable

RÉSUMÉ

Contexte : La stimulation du système de conduction (ou CSP pour *Conduction System Pacing*) est recommandée lorsqu'une charge de stimulation ventriculaire élevée est prévue et comme solution de rechange à la resynchronisation cardiaque. De nombreuses études ont montré l'importance d'obtenir une CSP plutôt qu'une stimulation septale profonde, et les résultats cliniques supérieurs qui lui sont associés. Plusieurs critères sont actuellement reconnus pour vérifier le positionnement d'une sonde de CSP; ceux-ci nécessitent tous l'utilisation d'un système d'électrophysiologie (EP). Les systèmes d'EP ne sont pas aisément accessibles, ce qui limite la pose de sondes de CSP aux hôpitaux de soins tertiaires et aux centres spécialisés. Le but de cette étude consistait à établir les critères uniquement basés sur l'ECG permettant de confirmer la capture par CSP et d'améliorer ainsi l'accès à cette technique de stimulation.

Méthodologie : Nous avons extrait rétrospectivement toutes les tentatives d'implantation d'une sonde de CSP dans notre centre. Les critères établis pour la CSP ont été évalués pour chaque patient, ainsi que la présence de caractéristiques visibles uniquement à l'ECG.

Résultats : La présence de trois critères basés uniquement sur l'ECG s'est avérée très prédictive d'une capture par CSP chez les patients sans antécédent de rythme stimulé : une onde S terminale en V_5 - V_6 , un segment ST isoélectrique en V_6 et une onde T positive en V_5 - V_6 . Lorsqu'appliqués à des patients présentant un rythme de base non stimulé et un intervalle inter-pics V_6 - $V_1 > 44$ ms, ces critères ont montré une exactitude prédictive de 80,4 %, avec une sensibilité de 87,8 % et une spécificité de 76,5 %.

Keywords: conduction system pacing; criteria; electrocardiography

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Although cardiac resynchronization therapy (CRT) remains the standard of care for patients with heart failure and electrical dyssynchrony, several ongoing studies aim to identify patient subgroups in which conduction system pacing (CSP) may provide greater clinical benefit and potentially complement or replace conventional CRT. Currently, CSP is recommended in patients with expected high ventricular pacing burden and as an alternative to CRT.¹⁻³ CSP is an umbrella

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confirmation of capture without the need for EP systems, thereby expanding patient access to this physiologic pacing strategy.

term involving His bundle pacing (HBP) and left bundle branch area pacing (LBBAP).³ LBBAP can be further subdivided into left bundle branch pacing (LBBP), left fascicular pacing, and left ventricular septal pacing (LVSP).³ Although both HBP and LBBAP techniques have prevented pacing-induced cardiomyopathy by right ventricular pacing (RVP), LBBAP has been found to preserve and restore intraventricular left ventricle synchrony.³ Observational data comparing the 2 techniques have indicated that the success rates, capture thresholds, sensing amplitude, and lead complication rates are more favourable with LBBAP, whereas acute hemodynamic improvement and clinical outcomes, including left ventricular ejection fraction (LVEF), heart failure, and mortality outcomes, are comparable.³ In clinical practice, preferential adoption of LBBAP over HBP has occurred over the years due to the more favourable electrical parameters and perceived ease of implantation.³

Multiple studies have underscored the clinical importance of achieving CSP capture, as opposed to deep septal pacing alone. In 2024, Zhu et al. compared outcomes among patients undergoing LBBP, LVSP, or biventricular pacing (BiVP).⁴ LBBP was associated with lower all-cause mortality, fewer heart failure hospitalizations, and a reduced incidence of malignant ventricular arrhythmias when compared with BiVP.⁴ Although outcomes in the LVSP cohort were markedly worse, the authors noted that this group largely comprised patients who had failed LBBP or BiVP, suggesting a higher risk population with potential septal fibrosis or distal conduction block.⁴ Accordingly, LVSP should be interpreted as a selected cohort rather than a direct comparator.⁴ Notwithstanding this limitation, the observed differences between LBBP and BiVP support the superior clinical performance of LBBP in reducing mortality and heart failure-related events. Consistent with these findings, the 2025 Multi-centre European Left Bundle Branch Area Pacing Outcomes Study (MELOS) RELOADED study, led by Jastrzębski et al., demonstrated a significant survival advantage using LBBAP when compared with RVP, with early and sustained separation of survival curves.⁵ LBBAP was also associated with a lower incidence of heart failure hospitalization and emerged as an independent predictor of improved survival.⁵ Collectively, these findings reinforce the importance of achieving reliable CSP capture, which is consistently associated with meaningful reductions in mortality and heart failure hospitalizations.

In 2022, the MELOS study by Jastrzębski et al. identified various electrophysiologic criteria related to LBBAP success, including the QRS transitions at threshold (and during programmed stimulation), V₆ R-wave peak time (RWPT), and V₆-V₁ interpeak interval time.⁶ Although the

Conclusions : Ces résultats indiquent que la réussite de la capture par CSP peut être confirmée de manière fiable à l'aide d'une combinaison de marqueurs simples basés sur l'ECG chez les patients sans stimulation ventriculaire antérieure. La mise en œuvre de ces critères pourrait faciliter une adoption plus large de la CSP en permettant une confirmation fiable de la capture sans recourir à un système d'EP, élargissant ainsi l'accès des patients à cette technique de stimulation physiologique.

QRS transition at threshold test remains the gold standard for LBB capture, it was only seen in 26.4% of MELOS patients,⁶ which led to the development of CSP criteria using more specialized measurements. Interpretation of the V₆ RWPT may be limited, as a prolonged value can reflect not only absence of LBB capture but also initial latency, slowed conduction through a diseased His-Purkinje system, significant left ventricular dilatation, or a combination of these factors.⁷ In contrast, the V₆-V₁ interpeak interval time is less likely influenced by these limitations, although the consensus is that the combination of these criteria improves the diagnostic yield of electrocardiographic (ECG) analysis.^{2,7}

There are various accepted criteria to ascertain CSP lead placement, which all currently require an electrophysiology system,² limiting CSP lead placement to specialized centres. Despite clear ECG differences between CSP and deep septal pacing (DSP) (Fig. 1), there have been very few studies performed on ECG-only criteria concerning CSP success. In 2024, Jastrzębski et al. identified possible ECG criteria to validate LBBP, such as normalization of ST-T in V₅-V₆ and lead I, and the presence of terminal S waves in V₅-V₆ and lead I, based on a cohort of 164 patients.⁸ At this time, the identified criteria have not been otherwise validated.⁸ In 2025, Cano et al. found that a steep QRS upslope and a slurred/notched QRS downstroke or "M" pattern in the inferior leads helped identify LBB capture during LBBAP in their study of 115 patients with baseline narrow QRS and/or without cardiomyopathy.⁹

The purpose of this study was to identify ECG-only CSP criteria leading to a successful implant, to help democratize CSP adoption.

Methods

Patient data

All CSP attempted implants by a single operator from January 2018 to May 2025 at the University Hospital of Sherbrooke (Sherbrooke, QC, Canada) were reviewed. This retrospective cohort study was approved by the ethics committee of University Hospital of Sherbrooke (Authorization No. 2026-6025), with no individual consent required beyond the standard consent obtained at the time of implantation. Various accepted criteria for CSP capture were evaluated for each patient, along with the presence of ECG-only criteria at a standard paper speed (25 mm/s): a terminal S wave in lead I; T-wave polarity in lead I; an initial r wave in V₁; any r'/R' in V₁; a terminal S wave in lateral leads (V₅-V₆); an isoelectric ST segment in V₆; and T-wave polarity in the lateral leads, as visual-only criteria to CSP capture

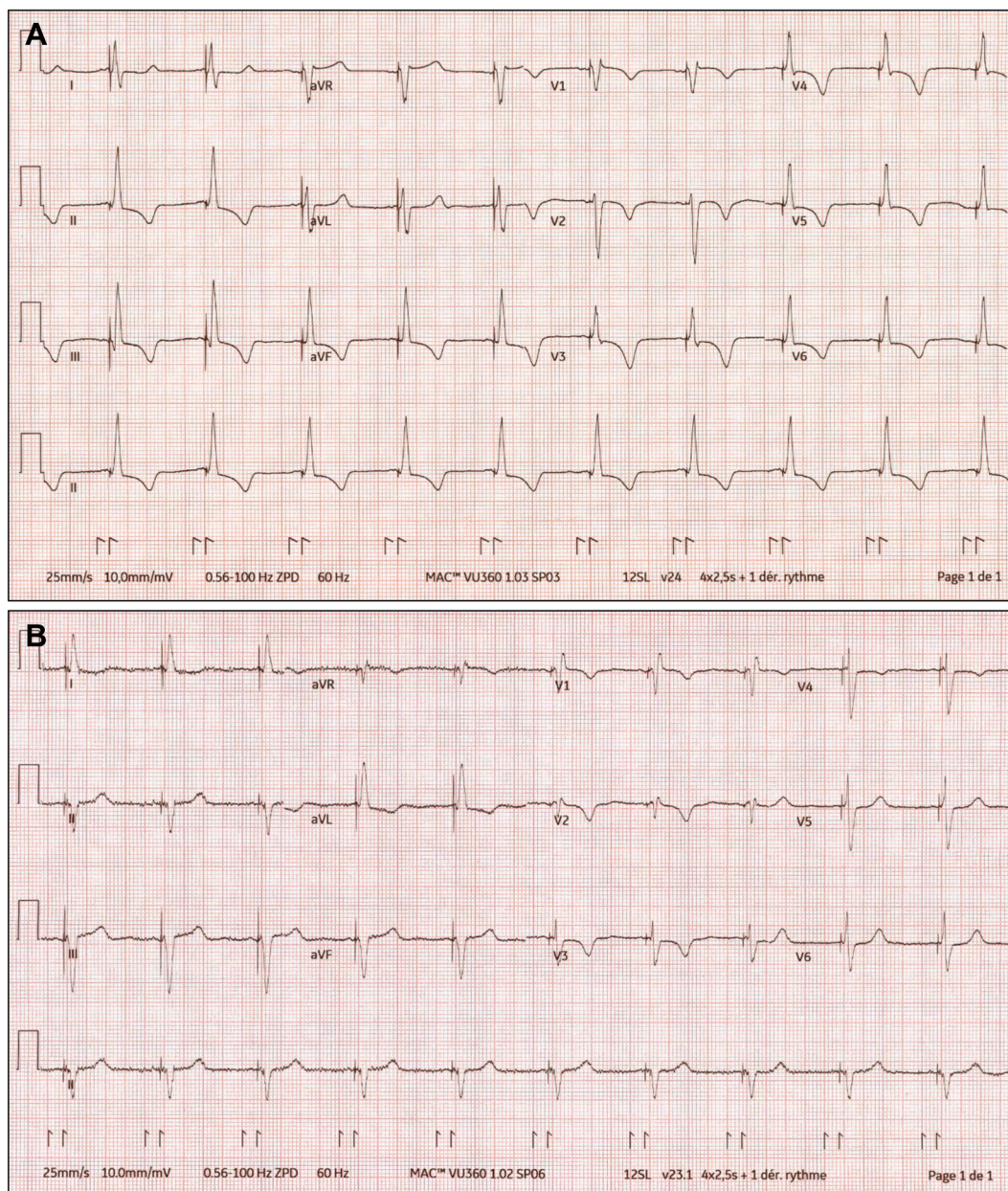


Figure 1. Representative electrocardiograms demonstrating (A) deep septal pacing vs (B) conduction system pacing in patients with a preimplantation left bundle branch block morphology.

(Table 1 and Fig. 2). Although the transition in QRS morphology is considered the gold standard for CSP,² in this retrospective study we included data dating back to January 2018, prior to publication of any CSP guidelines. Consequently, although QRS transitions were sometimes seen at implantation, they were not systematically recorded. The V_6 - V_1 interpeak interval was considered the gold standard for its availability within the data set and ease of measurement, in addition to being less susceptible to the limitations and overlapping of V_6 RWPT values.⁷ Patients were divided into 3 distinct groups based on the V_6 - V_1 interpeak interval: > 44 ms; 34-43 ms; and ≤ 33 ms, as per current published criteria for CSP capture.²

The anteroposterior orientation of the pacing lead was determined based on inferior lead polarity (leads II, III, and augmented vector foot -aVF). The lead was classified as posteriorly directed when all 3 inferior leads were negative and as anteriorly directed when all 3 were positive. Any other combination of inferior lead polarities (negative, positive, or isodiphasic) was classified as midseptal positioning.

Data analysis

Nominal and dichotomous variables are presented as frequency (percent), whereas continuous variables are presented as mean (standard deviation) or median [interquartile range],

Table 1. Electrophysiology criteria evaluated per patient

Current published criteria for CSP capture*	ECG-only criteria
LBBP • V_6-V_1 interpeak interval > 44 ms • V_6 RWPT < 75 ms (native narrow QRS or isolated RBBB) • V_6 RWPT < 85 ms (LBBB, IVCD, RBBB + fascicular block, wide escape rhythm, asystole) Likely LBBP • V_6-V_1 interpeak interval > 33 ms • V_6 RWPT < 85 ms (native narrow QRS or isolated RBBB) • V_6 RWPT < 100 ms (LBBB, IVCD, RBBB + fascicular block, wide escape rhythm, asystole)	• Terminal S wave in lead I • T-wave polarity in lead I • Initial r wave in V_1 • Terminal r'/R' in V_1 • Terminal S wave in lateral leads (V_5-V_6) • Isoelectric ST segment in V_6 • T-wave polarity in lateral leads (V_5-V_6)

The gold standard comparator was the V_6 - V_1 interpeak interval.
IVCD, intraventricular conduction delay; LBBAP, left bundle branch area pacing; LBBB, left bundle branch block;
LVSP, left ventricular septal pacing; RBBB, right bundle branch block; RBBP, right bundle branch pacing; RWPT,
R-wave peak time; s-LBBP, selective left bundle branch pacing.
* From Burri et al.²

depending on data distribution. No imputation methods were applied, and the missing data were reported as observed. A significance level of 5% was used throughout. All analyses were performed using R version 4.4.2 (R Foundation for Statistical Computing, Vienna, Austria).

The incidence of each ECG-based criterion was calculated across patient groups and assessed in combination to identify the optimal set of ECG criteria corresponding to CSP capture. The Fisher exact test was used to evaluate associations between each criterion and V_6 - V_1 interpeak groups. To assess the diagnostic performance of the ECG-based criteria (terminal S wave in leads V_5 - V_6 , isoelectric ST segment in V_6 , and positive T wave in leads V_5 - V_6), confusion matrices were constructed. Sensitivity, specificity, and overall predictive accuracy were calculated, each with corresponding 95% confidence intervals.

Results

A cohort of 697 consecutive patients was evaluated (Table 2), 37.9% of whom were women. Their mean age was 77.8 (standard deviation 8.8) years, with a range of 22-98 years. Implant indications included: sick sinus syndrome (28.6%), atrioventricular (AV) block (33.7%), abnormal conduction—induced cardiomyopathy (22.8%), AV node ablation (9.6%), and LBBB only (with a decreasing ejection fraction < 35%) (2.3%). Only Medtronic 3830 (Medtronic, Minneapolis, MN, USA) leads were implanted. His pacing was targeted in 4.0% of patients, and 40.5% of patients had preimplant narrow QRS. Leads were directed anteriorly,

posteriorly, and midseptally in 28.3%, 21.6%, and 50.1% of cases, respectively, based on inferior lead polarities. A QRS measured including the pacing spike of ≤ 140 ms was achieved in 73.6% of implants. A left ventricular activation time (LVAT) of < 75 ms was achieved in 45.8% of patients, < 85 ms in 73.9% of patients, and could not be evaluated in 4.0% of patients due to a QS morphology in V_6 . The V_6 - V_1 interpeak interval could not be measured in 37.4% of patients due to the lack of R'/r' in V_1 and apical lead placement preventing LVAT measurement. However, among patients with measurable values, an interpeak of > 33 ms was achieved in 72.5% of patients, corresponding to 45.3% of the complete cohort.

The incidence rate of the evaluated ECG-only criteria (terminal S wave in lead I, T-wave polarity in lead I, initial r wave in V_1 , any terminal r'/R' in V_1 , terminal S wave in V_5 - V_6 , isoelectric ST segment in V_6 , and T-wave polarity in V_5 - V_6), stratified by V_6 - V_1 interpeak patient group, is presented in Table 3.

Considering a cutoff incidence rate of 80%, selected *a priori* as clinically relevant, it was found that the presence of a terminal S wave in V_5 - V_6 , an isoelectric ST segment in V_6 , and a positive T wave in V_5 - V_6 were the most helpful ECG parameters in obtaining a V_6 - V_1 interpeak > 44 ms, indicating successful LBB pacing.² Thus, the combined effects of the presence of a terminal S wave in V_5 - V_6 , an isoelectric ST segment in V_6 , and a positive T wave in V_5 - V_6 were further assessed. Given the known pacemaker-related cardiac memory effect on T-wave morphology,¹⁰ the study population was stratified into 2 subgroups based on preimplant QRS

ECG criteria evaluated per patient:

1. Terminal S wave in Lead I
2. T wave polarity in Lead I
3. Initial R wave in V_1
4. r'/R' in V_1
5. Terminal S wave in $V_5 - V_6$
6. Isoelectric ST segment in V_6
7. T wave polarity in $V_5 - V_6$

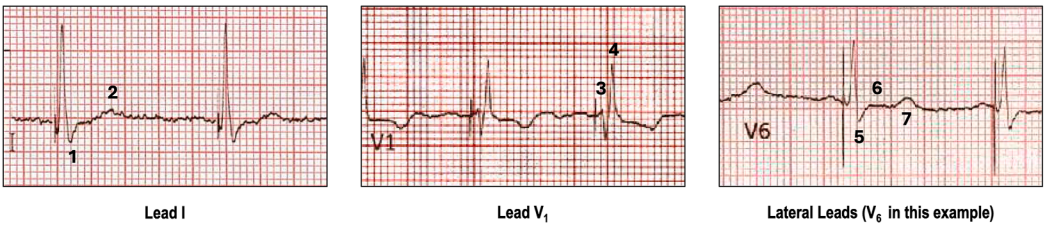


Figure 2. Electrocardiography-only criteria evaluated per patient.

Table 2. Patient population baseline characteristics

Patient characteristics	Value
Sex, n (%)	
Female	264 (37.9%)
Male	433 (62.1%)
Age, years	77.8 (8.8)
Age range, years	22-98
Pacemaker indication, n (%)	
Sick sinus syndrome	199 (28.6%)
AV node block	235 (33.7%)
AiCM	159 (22.8%)
AV node ablation	67 (9.6%)
LBBB only*	16 (2.3%)
Preimplant QRS morphology, n (%)	
Normal	248 (35.6%)
LBBB	133 (19.9%)
RBBB	125 (17.9%)
IVCD	67 (9.6%)
Paced rhythm	124 (17.8%)
Pacing target, n (%)	
His	28 (4.0%)
LBB	669 (96.0%)
Lead position, n (%)	
Anterior	190 (28.3%)
Posterior	145 (21.6%)
Midseptal	337 (50.1%)
Preimplant QRS, ms, mean (SD)	132.0 (38.3)
Narrow preimplant QRS	40.5%
Postimplant QRS, ms, n (%)	135.0 (18.9)
Narrow postimplant QRS	27.1%
LVAT, ms, mean (SD)	
Total cohort (including paced rhythm)	76.2 (15.1)
Normal	71.8 (13.0)
LBBB	76.5 (14.6)
RBBB	75.5 (13.9)
IVCD	81.3 (16.1)
LVAT < 75 ms, n (%)	
Total cohort (including paced rhythm)	311 (45.8%)
Normal	144 (58.1%)
LBBB	54 (40.6%)
RBBB	59 (47.2%)
IVCD	21 (31.3%)
LVAT < 85 ms, n (%)	
Total cohort (including paced rhythm)	511 (73.9%)
Normal	203 (81.9%)
LBBB	102 (90.2%)
RBBB	91 (72.8%)
IVCD	42 (62.7%)
LVAT < 100 ms, n (%)	
Total cohort (including paced rhythm)	600 (86.1%)
LBBB	120 (90.2%)
IVCD	59 (88.1)
V ₆ -V ₁ interpeak, ms, mean (SD)	40.1 (10.9)
V ₆ -V ₁ interpeak	
≤ 33 ms	120 (17.2% of total, 27.5% of measured)
34-44 ms	157 (22.5% of total, 36.0% of measured)
> 44 ms	159 (22.8% of total, 36.5% of measured)
Unmeasurable	261 (37.4% of total)

AiCM, abnormal conduction induced cardiomyopathy; AV, atrioventricular; IVCD, intraventricular conduction delay; LBBAP, left bundle branch area pacing; LBBB, left bundle branch block; s-LBBP, selective left bundle branch pacing; LVAT, left ventricular activation time; LVSP, left ventricular septal pacing; RBBB, right bundle branch block; RBBP, right bundle branch pacing; RWPT, R-wave peak time; SD, standard deviation.

* LBBB without AiCM criteria (patients with a decreasing ejection fraction, yet > 35%).

morphology: 1) paced rhythm and 2) other rhythms. The results of this subgroup analysis are presented in Table 4.

As shown in Table 4, the 3 ECG-only criteria (terminal S wave in V₅-V₆, isoelectric ST segment in V₆, and positive T wave in V₅-V₆) were predominantly observed in patients with V₆-V₁ interpeak intervals > 33 ms and without previously paced baseline rhythms.

In patients with unpaced rhythms and V₆-V₁ interpeak intervals > 44 ms, application of the 3 ECG-only criteria yielded a predictive accuracy of 80.4%, with a sensitivity of 87.8% and a specificity of 76.5%. Moreover, among patients without previously paced rhythms and with interpeak intervals > 33 ms, the presence of the 3 ECG-only criteria demonstrated a predictive accuracy of 73.2%, with a sensitivity of 63.2% and a specificity of 98.9%. These values are presented in Table 5.

A sex-disaggregated analysis was performed to compare the predictable accuracy, sensitivity, and specificity of the ECG-only criteria. As shown in Table 6, no statistically significant sex-based differences were observed in predictive accuracy, sensitivity, or specificity.

Discussion

As previously mentioned, it is of utmost important to achieve CSP rather than deep septal pacing alone.^{4,5} Although the gold standard to achieve a successful CSP according to the consensus by Burri et al. includes QRS transitions during threshold testing at implant,² these transitions were found to be present in only 26.4% of patients according to the MELOS study,⁶ indicating CSP lead implantation is challenging even within specialized centres. In addition, easier confirmatory measurements, such as V₆-V₁ interpeak > 40 ms, was identified in only 18.3% of MELOS patients.⁶ Notably, within this cohort, one third of patients had unmeasurable interpeak values, further highlighting the difficulty of reliably confirming CSP.

The presence of 3 ECG-only criteria (terminal S wave in V₅-V₆, isoelectric ST segment in V₆, and positive T wave in V₅-V₆), however, was highly predictive of conduction system pacing capture in patients without a previously paced rhythm, with no observed sex-related differences. The mechanistic basis for this predictive value can be considered for each criterion. The terminal S wave in lateral leads is an indicator that the conduction system has been engaged or is in close proximity, as a normal QRS complex is polyphasic, and even a right bundle branch block, using the normal left bundle, produces a terminal S wave in lateral precordial leads. In contrast, terminal S waves are absent in monophasic QRS rhythms, such as in premature ventricular beats or ventricular tachycardia, where the propagation of depolarization does not fully occur within the conduction system or left bundle. The isoelectric ST segment and positive T wave reflect normal repolarization, which is expected only when depolarization occurs via the intrinsic conduction system. During implantation, the presence of a terminal S wave in V₅-V₆ without fully normalized repolarization suggests that a portion of ventricular activation is still occurring through myocardial tissue (ie, nonselective LBB capture). In such cases, minor further advancement of the lead tip may result in

Table 3. Incidence rate of ECG only parameter per V₆-V₁ interpeak group

ECG-only criterion	V ₆ -V ₁ interpeak			P value
	≤ 33 ms (n = 120)	34-44 ms (n = 157)	> 44 ms (n = 159)	
Initial R wave in V ₁	12 (10.2%)	39 (27.5%)	60 (44.4%)	< 0.001
Terminal S wave in lead I	34 (28.8%)	68 (47.9%)	90 (66.7%)	< 0.001
Terminal S wave in V ₅ -V ₆	29 (24.6%)	120 (83.9%)	130 (97.0%)	< 0.001
Isoelectric ST segment in V ₆	10 (8.5%)	93 (65.5%)	112 (83.6%)	< 0.001
Positive T wave in lead I	43 (36.4%)	92 (64.3%)	97 (71.9%)	< 0.001
Positive T wave in V ₅ -V ₆	12 (10.0%)	109 (69.9%)	132 (83.0%)	< 0.001

Data expressed as number (percent).

ECG, electrocardiography.

Table 4. Presence of ECG-only criteria (terminal S wave in V₅-V₆, isoelectric ST segment in V₆, and a positive T wave in V₅-V₆) in previously paced rhythms vs other rhythms per V₆-V₁ interpeak group at conduction system pacing implant

Presence of ECG-only criteria: • Terminal S wave in V ₅ -V ₆ • Positive T wave in V ₅ -V ₆ • Isoelectric ST segment in V ₆	Paced rhythm			Other (normal, LBBB, RBBB, and IVCD)		
	≤ 33 ms (n = 26)	34-44 ms (n = 23)	> 44 ms (n = 25)	≤ 33 ms (n = 94)	34-44 ms (n = 134)	> 44 ms (n = 134)
0 of 3 criteria	15 (57.7%)	2 (8.7%)	2 (8.0%)	59 (62.8 %)	6 (4.5%)	4 (3.0%)
1 of 3 criteria	11 (42.3%)	7 (30.4%)	16 (64.0%)	31 (33.0%)	23 (17.2%)	21 (15.7%)
2 of 3 criteria	0 (0%)	10 (43.5%)	3 (12.0%)	1 (3.2%)	55 (41.0%)	8 (6.0%)
3 of 3 criteria	0 (0%)	4 (17.4%)	4 (16.0%)	1 (1.1%)	50 (37.3%)	101 (75.4%)
Omitted patients due to unmeasurable V ₆ -V ₁ interpeaks		50			211	

Data expressed as number (percent).

ECG, electrocardiography; IVCD, intraventricular conduction delay; LBBB, left bundle branch block; RBBB, right bundle branch block.

complete normalization of repolarization and achievement of selective LBB capture.

During the implantation workflow, as the lead advances toward the left side of the interventricular septum, the left septal myocardium is activated slightly earlier than the right side. This results in the appearance of an r' wave in V₁, which typically increases in amplitude and duration as the lead is positioned further into the left septum, often producing a morphology resembling right bundle branch block. This pattern may arise from retrograde conduction via the right bundle branch, transeptal conduction to the right bundle, or a combination of both mechanisms. However, the presence or absence of an r'/R' wave in V₁ alone neither confirms nor excludes CSP. In this cohort, one third of patients without an r'/R' in V₁ demonstrated LVATs < 75 ms, and two thirds had LVATs < 85 ms, suggesting that CSP may still be achieved in these cases. When leads are positioned toward the anterior septum, an r'/R' in V₁ may be unmasked by repositioning the V₁ electrode from the fourth intercostal space to 1 or 2 lower intercostal spaces.¹¹ In such scenarios, ECG-based criteria incorporating both depolarization and

repolarization features in the lateral leads may help confirm CSP capture, particularly when r'/R' in V₁ is absent or when a QS pattern is present in the lateral leads.

The 3 ECG-based criteria indicated may be less reliable in patients with baseline abnormalities in QRS complex, ST-segment, or T-wave morphology that are not expected to be corrected after CSP implantation. In particular, these criteria appear suboptimal in patients with previously ventricular-paced rhythms, given the well-described cardiac memory effect, which can result in persistent T-wave inversions for several weeks after CSP upgrade.¹⁰ Other patient populations in whom these ECG criteria may be less effective include those with ischemic cardiomyopathy, left ventricular hypertrophy, or infiltrative cardiomyopathies, owing to chronic electrophysiologic alterations. In these conditions, baseline QRS morphology may affect the presence of terminal S waves, whereas ST-segment abnormalities and distorted T waves in the lateral leads may further limit interpretability.¹² In such cases, the alternative ECG features described by Cano et al. (including a steep QRS upslope and a slurred or notched QRS downstroke ["M"

Table 5. Predictive accuracy, sensitivity, and specificity of ECG-only criteria (terminal S wave in V₅-V₆, isoelectric ST segment in V₆, and a positive T wave in V₅-V₆) for patients with unpaced rhythms

V ₆ -V ₁ interpeak	Presence of 3 of 3 of the ECG-only criteria		
	Predictive accuracy	Sensitivity	Specificity
> 44 ms	80.4% [75.8%-84.3%] (n = 267 of 332)	87.8% [80.4%-93.2%] (n = 101 of 115)	76.5% [70.3%-82.0%] (n = 166 of 217)
> 33 ms	73.2% [68.2%-77.7%] (n = 243 of 332)	63.2% [56.7%-69.3%] (n = 151 of 239)	98.9% [94.2%-99.9%] (n = 92 of 93)

Data expressed as median [interquartile range].

ECG, electrocardiography.

Table 6. Comparison of predictive accuracy, sensitivity, and specificity of the ECG-only criteria (terminal S wave in V₅-V₆, isoelectric ST segment in V₆, and positive T wave in V₅-V₆) between sex in patients with unpaced rhythms

V ₆ -V ₁ interpeak	Sex	Presence of 3 of 3 of the ECG-only criteria		
		Predictive accuracy	Sensitivity	Specificity
> 44 ms	Male	81.4% [75.3%-86.7%] (n = 158 of 194)	85.7% [74.6%-93.2%] (n = 54 of 63)	79.4% [71.4%-86.0%] (n = 104 of 131)
	Female	79.0% [71.2%-85.5%] (n = 109 of 138)	90.4% [79.0%-96.8%] (n = 47 of 52)	72.1% [61.4%-81.2%] (n = 62 of 86)
	<i>P</i> value	0.6775	0.6342	0.2818
> 33 ms	Male	72.7% [65.8%-78.8%] (n = 141 of 194)	60.6% [51.7%-69.0%] (n = 80 of 132)	98.4% [91.3%-99.9%] (n = 61 of 62)
	Female	73.9% [65.8%-81.0%] (n = 102 of 138)	66.4% [56.5%-75.2%] (n = 71 of 107)	100.0% [88.8%-100.0%] (n = 31 of 31)
	<i>P</i> value	0.9012	0.4345	1

Data expressed as median [interquartile range].
ECG, electrocardiography.

pattern] in the inferior leads) may assist in identifying LBB capture.⁹ In addition, these criteria may not be applicable in patients with a QRS morphology characterized by QS complexes in leads V₅-V₆, such as in very apically directed implants (eg, fascicular pacing), where a terminal S wave in the lateral leads is absent. In these situations, the remaining ECG criteria, namely an isoelectric ST segment and normalization of T-wave polarity, may still provide supportive evidence of physiologic repolarization consistent with CSP. Last, this approach (relying on evidence of normal depolarization, as reflected by a polyphasic QRS complex with a terminal S wave in the lateral leads) has not yet been systematically evaluated in patients with more

advanced electrophysiologic disease. It remains to be determined whether the concept of preserved abnormal repolarization, reflecting baseline conduction disease, can be used alongside normalized depolarization features (eg, a polyphasic QRS complex with a terminal S wave in the lateral leads) to confirm CSP. For example, patients with hypertrophic cardiomyopathy may retain baseline ST-T abnormalities despite LBB engagement, whereas a pseudo-normalization of ST segment and T wave could suggest incomplete or nonselective CSP.

This study has several limitations. First, it is a single-centre, retrospective study involving a single operator. Second, the sensitivity and specificity of the ECG-based criteria

Current published criteria for CSP capture²:

LBBP:

- V₆-V₁ interpeak interval > 44 ms
- V₆ RWPT <75 ms (native narrow QRS or isolated RBBB)
- V₆ RWPT <85 ms (LBBB, IVCD, RBBB + fascicular block, wide escape rhythm, asystole)
- QRS transition to LVSP or s-LBBP at threshold test
- QRS transition to s-LBBP at programmed stimulation

Likely LBBP:

- V₆-V₁ interpeak interval > 33 ms
- V₆ RWPT <85 ms (native narrow QRS or isolated RBBB)
- V₆ RWPT <100 ms (LBBB, IVCD, RBBB + fascicular block, wide escape rhythm, asystole)
- QRS transition to with V₆ RWPT prolongation by 10-14 ms at threshold test
- QRS transition to LVSP at programmed stimulation

LVSP:

- Qr/QR/qR in V₁

IVCD = intra-ventricular conduction delay; LBBAP = left bundle branch area pacing; LBBB = left bundle branch block; s-LBBP = selective left bundle branch pacing; LVSP = left ventricular septal pacing; RBBB = right bundle branch block; RBBP = right bundle branch pacing; RWPT = R-wave peak time; s-LBBP = selective left bundle branch pacing.

Proposed Simplified ECG Criteria for CSP capture:

1. Terminal S wave in V₅ - V₆
2. Isoelectric ST segment in V₆
3. Positive T wave polarity in V₅ - V₆



V ₆ -V ₁ interpeak:	Presence of 3/3 ECG criteria:		
	Predictive accuracy	Sensitivity	Specificity
> 44 ms	80.4%	87.8%	76.5%
> 33 ms	73.2%	69.3%	98.9%

*No statistically significant differences found between sex

Conclusion: Simple ECG markers reliably confirms CSP capture in patients without prior ventricular pacing

Central Illustration. Current published criteria for conduction system pacing capture (CSP) vs proposed simplified electrocardiography-only criteria for CSP capture.

were assessed using the V_6 - V_1 interpeak interval as the gold standard. Use of alternative established CSP criteria as comparators may yield different estimates of diagnostic performance. In addition, QRS transitions during threshold testing at the time of implantation were not systematically recorded because the study cohort dates back to January 2018, prior to publication of the Burri et al. consensus criteria.²

A larger, prospective study is planned to further validate these ECG-based CSP criteria. This upcoming study will include evaluation across specific patient populations, comparison with other established CSP criteria, and incorporation of a multicentre cohort involving multiple operators.

Conclusions

Conduction system pacing can be performed using 3 ECG-only criteria: 1) a terminal S wave in V_5 - V_6 ; 2) an isoelectric ST segment in V_6 ; and 3) a positive T wave in V_5 - V_6 , for patients with unpaced baseline rhythms. Implementation of these criteria may help to democratize CSP implantation by enabling reliable confirmation of CSP capture in centres without access to EP systems, thereby expanding patient access to this physiologic pacing strategy (see [Central Illustration](#)).

Further prospective studies comparing implantation outcomes using these ECG-based criteria vs currently accepted CSP criteria incorporating EP systems are warranted to validate their clinical utility.

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Ethics Statement

This retrospective cohort study was approved by the ethics committee of the University Hospital of Sherbrooke (Authorization No. 2026-6025). The study has adhered to the guidelines of the Centre de recherche du Centre Hospitalier Universitaire de Sherbrooke.

Patient Consent

The authors confirm that patient consent is not applicable to this article because it was a retrospective study.

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Disclosures

The authors have no conflicts of interest to disclose.

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