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Real-world adoption of left bundle branch area pacing: Insights from the Conduction-System pacing Italian Network Group (C-SING)

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Abbreviations list: AF, Atrial fibrillation; HBP, His bundle pacing; CRT, Cardiac resynchronization therapy; CSP, Conduction system pacing; LAFP, Left anterior fascicle pacing; LBB, left bundle branch; LBBAP, Left bundle branch area pacing; LBBP, Left bundle branch pacing; LPFP, Left posterior fascicle pacing; LSFP, Left septal fascicle pacing; LVAT, Left-ventricle activation time; LVSP, Left ventricular septal pacing.

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ABSTRACT

Background and objective: Left bundle branch area pacing (LBBAP) is increasingly used for treating bradycardia and heart failure. However, real-world data are limited. The Conduction-System Pacing Italian Network Group (C-SING) collected prospective data on LBBAP procedures in a nationwide context.
Methods: Observational data from 28 Italian sites were analysed for consecutive LBBAP procedures, comparing outcomes based on operator experience levels.
Results: From January 2022 to December 2023, 1250 patients (median age 78, 66.2 % male) underwent LBBAP attempt. Most frequent indications were atrioventricular block (40.8 %) and heart failure (25.6 %). Successful lead implantation was achieved in 1207 procedures (96.6 %), with a median fluoroscopy time of 6.2 min. Significant QRS duration reduction was observed in patients with interventricular conduction delay (144 ms to 120 ms, $p < 0.001$). Compared to low-experience operators (0–10 previous cases), high-experience operators (>50 cases) had significantly better outcomes, with reduced fluoroscopy time (5.9 min versus 9.0 min, $p = 0.005$) and an 86 % lower risk of lead implantation failure (adjusted odds ratio 0.14, $p = 0.002$). Periprocedural complications occurred in 6.2 % of patients, unaffected by operator experience. Follow-up data for 794 patients over a median of 93 days showed stable LBBAP pacing parameters and a 1.3 % loss of LBBAP capture.
Conclusions: LBBAP is routinely adopted for bradycardia and heart failure indication, with high success and acceptable complication rates, even when performed by less experienced operators. However, procedure outcomes improved significantly as operators gained experience with at least 50 prior cases. Electrical parameters remained stable with a low rate of LBBAP loss during short-term follow-up.

1. Introduction

Left bundle branch area pacing (LBBAP), firstly described by Hou X. et al. in 2019 as a feasible and effective strategy for conduction system pacing (CSP) of the heart [1], is increasingly being adopted in different clinical settings. In 2021, the European Society of Cardiology (ESC) guidelines on cardiac pacing [2] still regarded it as an emerging indication due to the lack of supporting clinical evidence. However, following the publication of the European Heart Rhythm Association (EHRA) consensus in 2023 [3] and the Heart Rhythm Society (HRS) guidelines on cardiac physiological pacing for the avoidance and mitigation of heart failure [4], more operators have adopted LBBAP as a standardized and routine technique.

The MELOS study [5] was the first to describe how LBBAP is adopted across Europe, reporting an acceptable incidence of complications and a high rate of procedural success. However, it included data from experienced centres only, raising some doubts about its potential for wider adoption. In addition, contrasting data are reported about the minimum number of performed cases to become confident with the technique, with a range between 50 and 150 [3,5,6]. More recent studies have compared LBBAP to conventional pacing and to cardiac resynchronization therapy (CRT) via biventricular pacing [7,8], confirming a very favourable safety and feasibility profile in mid-term follow-up. Promising evidence now suggests that LBBAP is beneficial in preventing pacing-induced cardiomyopathy in patients with anti-bradycardia pacing [9–11]. This may simplify ablate and pace procedures for uncontrolled, refractory atrial fibrillation (AF) and may be equivalent to conventional CRT in terms of cardiac function improvement and clinical response in heart failure patients. There is great anticipation regarding the capability of LBBAP to effectively treat so-called dromotropathy [12] by achieving atrioventricular resynchronization without the risk of electrically induced desynchrony associated with conventional myocardial pacing and the increased complexity and complications of biventricular CRT [13].

Several groups in Italy were early adopters of LBBAP [14]. Consequently, we established the Conduction System Pacing Italian Network Group (C-SING) to enable the prospective, consecutive collection of CSP procedure data via a standardized, shared platform in a real-world clinical context.

2. Methods

The C-SING is an ongoing independent, prospective, observational study enrolling consecutive patients who underwent an attempt of LBBAP implantation at 28 Italian sites for any indication. The first patient was included in January 2022, and for the purpose of this analysis, the database was frozen in December 2023. All beginner implanters aiming to enter C-SING underwent training through peer-to-peer onsite proctoring, theoretical instruction, and attendance at high-volume centers, focusing on implantation techniques and ECG evaluation, before starting the CSP program at their own sites.

The study protocol was approved by the Ethical Committee of the coordinating institution. The study complies with the Declaration of Helsinki, and all patients signed informed consent to participate.

2.1. Study objective and data collection

The objective of this analysis was to investigate LBBAP indications, procedural characteristics including the success rate, and periprocedural and short-term complications of LBBAP procedures in clinical practice, comparing operators with different levels of experience with this technique.

Participating sites were asked to include in the registry consecutive patients indicated for permanent cardiac pacing who underwent an attempt of LBBAP implantation with any commercially available delivery sheath and pacing lead (lumenless or stylet-driven) according to their routine care. Baseline patient characteristics and procedure-related characteristics, including fluoroscopy and procedure times, and electrical measurements of the LBBAP lead were collected and analysed for the periprocedural analysis. The LBBAP experience of the first operator was reported for each procedure according to the following classification: low (0–10 previous cases), intermediate (10–50 previous cases), and high (>50 previous cases), counting on cases from the first case for each enrolling centre. At the end of the procedure, LBBAP lead implantation was defined as successful according to QRS morphology during unipolar pacing. As enrolment started in 2022, the criteria described first by Huang W. et al. and then validated by subsequent studies were applied [15–18]: incomplete right bundle branch (RBB) block morphology in V1 lead and left-ventricle activation time (LVAT) <80 msec (or < 90 msec in case of bundle branch block at baseline) in V6 lead were pursued, with "fixation beats" (RBBB premature ventricular beats during lead screwing), QRS transition during threshold test, direct recording of LBB potential and interpeak delay (R in V6 lead – r' in V1 lead interval) >33 ms as bonus criteria. EHRA Consensus on CSP [3] was published during enrolment: investigators were therefore asked to classify the new procedures and previously collected cases according to the new standard criteria. The type of LBBAP capture was further categorized as follows: (i) left bundle branch pacing (LBBP), paced QRS morphology with a RBB delay or complete normalization of LBB block; (ii) left anterior fascicle pacing (LAFP), paced QRS morphology with RBB delay and an left posterior fascicle block pattern, right axis deviation, dominant R wave in the inferior leads, and dominant S wave in leads I and aVL; (iii) left posterior fascicle pacing (LPFP), paced QRS morphology with RBBD and a left anterior fascicle block pattern, left superior axis, dominant R wave in leads I and aVL, and dominant S wave in the inferior leads; (iv) left septal fascicle pacing (LPFP), paced QRS morphology with RBBD and intermediate QRS axis, lead II predominantly positive and lead III with negative component; (v) left ventricular septal pacing (LVSP), terminal R-wave in V1 lead, deep septal position of the lead in the basal to mid-septal area, and absence of criteria for direct capture of LBB. If the application of the EHRA consensus algorithm [3] for confirming conduction system capture indicated "likely LBBP," the procedure was considered successful; however, further subclassification of LBBAP capture was not performed.

Follow-up data were also collected. Sites were required to report any follow-up visits of patients performed according to clinical practice, including device interrogations and ECG recording. Data of interest during follow-up included ECG-based confirmation of effective LBBAP (i.e., maintenance of paced QRS morphology and duration compared to the QRS after successful implantation), electrical parameters of the LBBAP lead, and duration of paced QRS. The registry also collected all procedure- and device-related periprocedural complications (i.e., those occurring before hospital discharge) and those occurring during follow-up.

2.2. Statistical analysis

Binary and categorical data were presented as absolute and relative frequencies, while continuous variables were expressed as median and interquartile range (IQR). Predictors of LBBAP lead implantation failure were initially studied with univariable mixed-effects logistic regression models using the investigational site as a random effect variable. Statistically significant predictors were then included in a multivariable model. Results were reported as odds ratios (OR) along with 95 % confidence intervals (CI). Differences among independent groups were assessed using non-parametric tests for continuous variables and the Pearson's chi-square test for binary variables. Post-hoc Bonferroni correction was applied for multiple comparisons. In the follow-up analysis, for within-patient changes in electrical parameters and paced QRS duration, the Wilcoxon matched-pairs signed-rank test was used. All *p*-values were based on two-tailed tests of significance, with a threshold of <0.05 considered significant. Data were analysed using Stata software version 17.0 (StataCorp, TX).

3. Results

3.1. Study population

A total of 1256 patients were enrolled across 28 Italian centers, from January 2022 to December 2023. After excluding 6 patients due to missing data, 1250 patients who underwent device implantation with LBBAP attempt were included in the periprocedural analysis (Supplementary material, Fig. S1). Sixty-six percent of the patients were male, with a median age of 78 years [IQR, 72–83]. Complete baseline characteristics are reported in Table 1. About half of the patients had an antibradycardia indication with no structural heart disease, with atrioventricular block in sinus rhythm (46.0 %) and slow-rate AF (10.8 %) being the most frequent pacing indications. Patients with heart failure indication were also well represented (25.6 %), as indicated by the left ventricular ejection fraction (55 % [IQR, 42 %–60 %]), New York Heart Association functional class (19.7 % of patients in class III or IV), and drug therapy at implantation.

Table 1
Patient characteristics ($N = 1250$).

Male sex	817 (65.9)
Age (years)	78 (72–83)
Body mass index (Kg/m^2)	26.2 (23.7–29.1)
NYHA functional class	
I	402 (43.4)
II	342 (36.9)
III-IV	183 (19.7)
LVEF (%)	55 (42–60)
Medical history/Comorbidities	
Cardiomyopathy	
None	526 (49.5)
Ischemic	236 (22.2)
Valvular	101 (9.5)
Dilated	81 (7.6)
Hypertensive	42 (3.9)
Other	76 (7.2)
Hypertension	898 (75.0)
History of AF	432 (40.7)
History of heart failure	372 (38.3)
Diabetes mellitus	339 (28.4)
Coronary artery disease	296 (24.8)
Renal disease	221 (20.8)
COPD	103 (9.7)
Previous ictus/TIA	78 (7.4)
Pre-implant ECG	
Sinus rhythm	810 (67.3)
AF	338 (28.1)
Other	55 (4.6)
AV Block	648 (58.5)
PR interval (ms)	200 (160–250)
QRS duration (ms)	123 (100–150)
QRS morphology	
Normal	504 (42.7)
Any interventricular conduction delay	
LBBB	286 (24.3)
RBBB	171 (14.5)
RBBB + left anterior fascicular block	112 (9.5)
Nonspecific intraventricular conduction defect	57 (4.8)
Left anterior or posterior fascicular block	49 (4.1)
Pacing indication	
AV block	569 (46.0)
Heart Failure	317 (25.6)
AF with bradycardia	134 (10.8)
Sinus node dysfunction	152 (12.3)
Other*	199 (16.1)
Medication therapy at discharge	
β blockers	582 (56.8)
Diuretics	551 (54.0)
Anticoagulants	500 (43.4)
ACE inhibitors	378 (37.0)
Antiplatelets	348 (30.3)
Ca Antagonists	216 (21.2)
ARBs	200 (19.6)
ARN inhibitors	122 (12.0)

Data are shown as median (interquartile range) and n (% calculated on non-missing data) for categorical variables.
ACE, angiotensin converting enzyme; ARBs, angiotensin receptor blockers; ARNI, angiotensin receptor-neprilysin; AF, atrial fibrillation; AV, atrioventricular; COPD, chronic obstructive pulmonary disease; ECG, elettrocardiogram; LBBB, left bundle branch block; LVEF, left ventricle ejection fraction, NYHA, New York Heart Association; RBBB, right bundle branch block; TIA, transient ischemic attack.
* Including atrioventricular node ablation and neurocardiogenic syncope.

3.2. Periprocedural analysis

Procedural characteristics are reported in Table 2. Overall, successful LBBAP lead implantation was achieved in 1207 procedures (96.6 %). The median procedural time was 70 min (IQR, 60–95), with a median fluoroscopy time of 6.2 min (3.3–11.0).

LBBAP was successfully achieved using the first selected delivery sheath in 92.7 % of cases. The successful delivery sheaths included the following models: Biotronik Selectra 3D (62.2 %), Medtronic C315 or C304 (30.0 %), Boston Scientific SSPC (6.9 %), and Abbott CPS (1.0 %).

Table 2
Procedure-related characteristics ($N = 1250$).

LBBAP lead implantation success rate	1207 (96.6)
LBBAP experience of the operator	
Low (0–10 CSP cases)	132 (10.6)
Intermediate (10–50 CSP cases)	312 (25.0)
High (>50 CSP cases)	803 (64.4)
Device type	
Pacemaker	981 (78.7)
CRT-P/-D	253 (20.3)
ICD	12 (1.0) *
Number of delivery sheaths used during the procedure	
0	1 (0.1)[a]
1	1111 (92.7)
2	80 (6.7)
3	7 (0.6)
LBBAP lead type	
Stylet-driven	721 (63.9)
Lumenless	407 (36.1)
Fluoroscopic time (min)	6.2 (3.3–11)
Procedure duration (min)	70 (60–95)
Visible LBB signal	356 (34.5)
“w” pattern in V1 before fixation	1014 (96.8)
Fixation beats during screwing	599 (69.2)
LBBAP capture subtypes	
LBBP	212 (22.5)
LPFP	217 (23.0)
LSFP	160 (17.0)
LAFP	119 (12.6)
LVSP	87 (9.2)
Unknown	147 (15.6)
Post-implant ECG	
Paced QRS duration (ms)	118 (105–130)
R' in V1	887 (88.3)
Pacing stimulus to V6 R-wave peak (ms)	74 (66–82)
V6-V1 interpeak interval (ms)	42 (33–50)
LBBAP electrical parameters	
R-wave amplitude (mV)	9.5 (7.0–12)
Capture threshold (V)	0.7 (0.5–1.1)
Pulse width (ms)	0.4 (0.4–0.5)
Pacing Impedance (Ohm)	644 (501–780)

Data are shown as median (interquartile range) and n (% calculated on non-missing data) for categorical variables.
CRT-P/-D, cardiac resynchronization therapy pacemaker/defibrillator; ICD, implantable cardioverter defibrillator; LBBAP, left bundle branch area pacing; LAFP, left anterior fascicle pacing; LBBP, left bundle branch pacing; LPFP, left posterior fascicle pacing; LSFP, left septal fascicle pacing; LVSP, left ventricular septal pacing.
* Dual-chamber ICD were used to obtain CRT-D in 12 cases with permanent atrial fibrillation, connecting LBBA lead to atrial port, and conventional shock lead to DF4 port, with AAI or DDD with long-AV delay programming.
[a] Successful LBBAP procedure performed without using a delivery sheath (paced QRS duration of 120 ms, V6-V1 interpeak interval of 48 ms, and pacing stimulus to V6 R-wave peak of 68 ms).

A stylet-driven lead was used in 63.9 % of procedures, while a lumenless lead was used in 36.1 %. The implanted LBBAP lead brands included: Biotronik Solia S (51.1 %), Medtronic SelectSecure 3830 (36.1 %), Boston Scientific Ingevity (9.3 %), and Abbott Tendril 2088TC (3.5 %). The left bundle branch (LBB) signal was recorded from the pacing lead in 34.5 % of patients, while a “W” pattern in V1 before fixation and fixation beats during screwing were observed in 96.8 % and 69.2 % of procedures, respectively. Less than a quarter (22.5 %) of patients had the lead implanted in the common trunk of the LBB. The majority showed left fascicular pacing (LPFP 23.0 %, LSFP 17.0 %, and LAFP 12.6 %) and a minority exhibited LVSP (9.2 %). QRS measurements were consistent with effective LBBAP with a pacing stimulus to V6 R-wave peak of 74 ms (IQR, 66–82) and a V6-V1 interpeak interval of 42 ms (IQR, 33–50). Pacing electrical parameters of the LBBAP lead were clinically satisfactory (details in Table 2). The median paced QRS duration was 118 ms (IQR, 105–130). Compared to the native QRS, a significant reduction in QRS duration was observed in patients with any interventricular conduction delay (144 ms [IQR, 130–160] vs. 120 ms [IQR, 108–130], $p < 0.001$), while a slight, non-clinical but significant increase occurred in narrow-QRS patients (98 ms [IQR, 90–106] vs. 116 ms [IQR, 103–128], $p < 0.001$) (Supplementary material, Fig. S2).

3.3. Effect of operator experience

Most procedure were performed by operators with high LBBAP experience (64.4 %), with operators of intermediate and low experience performing 25.0 % and 10.6 % of implantations, respectively. Both

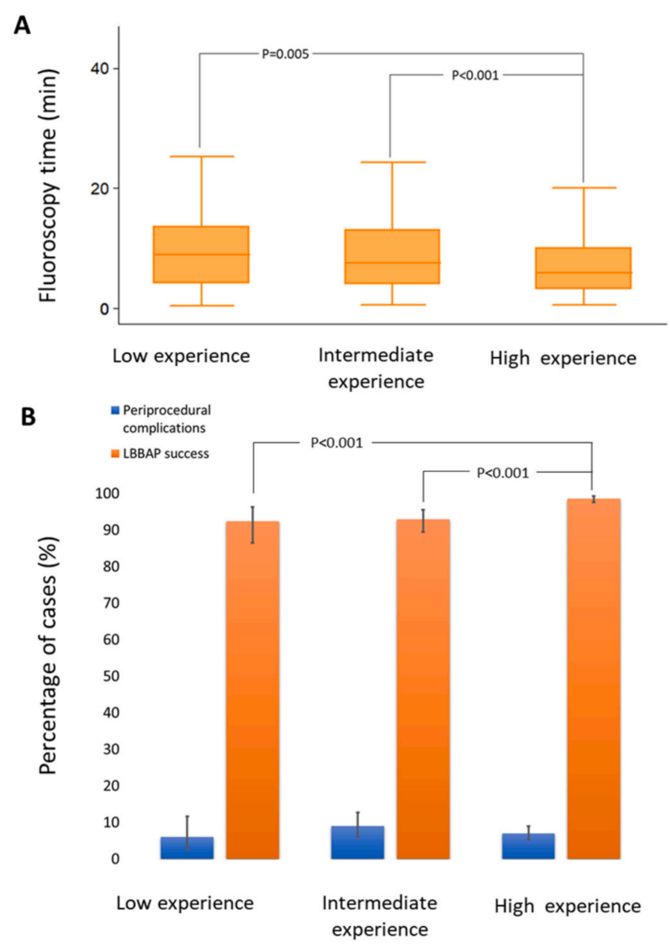

Fig. 1. Fluoroscopy time (A), LBBAP success rate and periprocedural complications (B) by experience of the operator. Only P values <0.05 after Bonferroni correction are displayed.

fluoroscopy time and lead implantation success rate were significantly affected by operator experience ($p < 0.001$) as depicted in Fig. 1. High-experience implanters achieved LBBAP using less fluoroscopy time than low-experience implanters (5.9 min [3.1–10.0] vs. 9.0 min [4.1–13.6] min, $p = 0.005$) and compared with intermediate-experience implanters (5.9 min [3.1–10.0] vs. 7.6 min [4.0–13.0] min, $p < 0.001$). Similarly, the LBBAP success rate was higher for high-experience implanters (98.6 %, CI: 97.6 %–99.3 %) compared to low-experience (92.4 %, CI: 86.5 %–96.3 %, $p < 0.001$) and intermediate-experience (92.9 % (CI: 89.5 %–95.5 %), $p < 0.001$). No significant differences were observed between low and intermediate levels of experience in either fluoroscopy time ($p = 0.483$) or success rate ($p = 0.840$). Fig. S3 in Supplementary material depicts probability of LBBAP success and fluoroscopy time based on the number of procedures for sites with operators of low and high experience at the beginning of enrollment. Results of univariable and multivariable analyses are reported in Table 3. The risk of LBBAP lead implantation failure was reduced by 86 % when the procedure was performed by a high-experience operator compared to a low-experience operator (OR 0.14, 95 %CI: 0.04–0.45, $p = 0.002$). Additionally, the presence of a LBB block, but not QRS duration per se, significantly reduced the risk of failure (OR 0.33, 95 %CI: 0.12–0.88, $p = 0.027$).

3.4. Follow-up analysis

Follow-up data were available for 794 patients, who were included in the follow-up analysis (Supplementary material, Fig. S1). After a median period of 93 days (IQR, 50–220) from successful LBBAP implantation, loss of CSP capture based on ECG assessment was observed in 10 patients (1.3 %). Specifically, loss of capture occurred in 2 patients due to LBBAP lead macro-dislodgement and in 8 patients who no longer met the LBBAP capture criteria [3].

In patients with confirmed LBBAP, electrical pacing parameters remained very satisfactory at follow-up (Supplementary material, Table S1). There was a statistically significant but clinically non-relevant increase in R-wave amplitude and a decrease in pacing threshold, as well as a greater decrease in unipolar pacing impedance. The paced QRS duration was stable (implantation 116 ms [IQR 104–128] vs. follow-up 117 ms [IQR, 102–127], $p = 0.820$).

Table 3
Univariable and multivariable models for LBBAP lead implantation failure using mixed effects logistic regression (N = 1250).

	Odds Ratio (95 % confidence interval), p value	
	Univariable	Multivariable
Experience of the operator*		
Intermediate	0.86 (0.36–2.05), 0.740	0.83 (0.34–1.98), 0.669
High	0.15 (0.05–0.50), 0.002	0.14 (0.04–0.48), 0.002
Age (year)	1.00 (0.97–1.04), 0.612	–
Female gender	0.85 (0.42–1.70), 0.645	–
Left ventricular ejection fraction (%)	0.99 (0.96–1.01), 0.470	–
QRS duration (ms)	0.99 (0.98–1.00), 0.214	–
Heart failure indication	0.86 (0.35–2.12), 0.745	–
Left Bundle Branch Block	0.33 (0.13–0.90), 0.029	0.33 (0.12–0.88), 0.027
Stylet-driven LBBAP lead	0.93 (0.40–2.36), 0.884	–

* Low experience as reference; low experience, 0–10 cases; intermediate experience, 10–50 cases; high experience, >50 cases.

3.5. Complications

Periprocedural complications were observed in 6.2 % of patients. The most frequent LBBAP lead-related events were intraprocedural perforation to left ventricular cavity with need for repositioning and no further consequences ($n = 35$, 2.8 %), pre-discharge LBBAP lead dislodgement leading to surgical revision ($n = 8$, 0.6 %), damage/entrapment of the helix lead during positioning ($n = 7$, 0.6 %), septal hematomas with spontaneous resolution in 48 h diagnosed at post-procedural echocardiography (n = 3, 0.2 %), and contrast impregnation of coronary veins/arteries ($n = 2$, 0.2 %). Other observed complications not related or only possible related to LBBAP are listed in Supplementary material, Table S2. Implanter experience did not impact the rate of periprocedural complications, as depicted in Fig. 1 ($p = 0.43$).

The rate of complications remained low even at follow-up (2.1 %) with two cases (0.2 %) of LBBAP lead dislodgements necessitating surgical revision at 55 and 224 days, respectively. Notably, a higher number of dislodgments was observed for atrial/ventricular leads ($n = 10$, 1.3 %).

4. Discussion

This study found that, firstly, LBBAP for bradycardia and heart failure demonstrated high success and low complication rates, even when performed by less experienced operators. Secondly, procedural outcomes improved as implanting physicians gained experience with at least 50 procedures. Lastly, electrical parameters in LBBAP remained stable during short-term follow-up.

As LBBAP is increasingly adopted in various clinical settings [19–21], monitoring its performance in real-life scenarios is crucial. Our registry confirmed that despite the lack of strong evidence on long-term efficacy and safety, this technique is already routinely used in many Italian sites not only for bradycardia pacing but also as a treatment for heart failure. CSP has now received a IIa or IIb class of recommendation for different groups of patients for the avoidance and mitigation of heart failure [4], suggesting further momentum in its widespread adoption.

One major concern among CSP experts is how to train new implanters and maintain high-quality procedures. One reason for the limited diffusion of His Bundle Pacing (HBP) was its long learning curve, increased procedural time, and concerns about less stable and satisfactory electrical measures. However, early adopters of HBP demonstrated its long-term safety and efficacy in highly experienced centers [22]. With consensus documents and trial results steadily accumulating, our study's findings on LBBAP seem reassuring. Contributions from new adopters (10.6 % of patients enrolled by low-experience implanters and 25 % by intermediate-experience ones) were significant. Although procedural success was lower for these groups, it was still high in absolute terms, exceeding 90 %. In the MELOS study, the learning curve was steepest for the initial 110 cases and plateaued after 250 cases [5]. This contrasts with the common observation that the technique can be easily performed by fellows and early-career physicians. Our study suggests that LBBAP can be safely and effectively applied from the beginning of the learning curve, given clearer and standardized procedural guidelines and the increasing availability of dedicated tools. Notably, complication rates did not vary based on the operator's experience level. However, after approximately 50 cases, we observed significant improvements in both fluoroscopy time reduction and procedural success. While our data cannot fully exclude the possibility that further learning curve gains may continue beyond 50 cases (Supplementary material, Fig. S4), creating a “supporting network” through scientific associations and teaching centers, as was done for most of the enrolling hospitals in C-SING, may be the best approach to ensure good results from the beginning.

The quality of LBBAP performed appears good, as evidenced by post-implant ECG measurements. Investigators were encouraged to apply the algorithm proposed by the EHRA consensus [3] to confirm LBBP/LVSP, and they were able to validate their results. Similar to findings from the MELOS study [5], most LBBAP cases in our study involved fascicular stimulation. However, we observed a higher proportion of LBB common trunk capture and a lower proportion of LVSP compared to MELOS. The reasons for these discrepancies remain unclear and warrant further investigation. One possible explanation could be the prior familiarity and extensive experience with HBP techniques at several participating sites in our study. Nevertheless, it is still uncertain whether variations in LBBAP techniques lead to differences in clinical outcomes [23].

As expected, the direct LBB signal was recorded in a minority of cases, although LBBAP could be validated via simpler ECG measures. Conversely, thorough assessment for the best "landing zone" on the right aspect of the interventricular septum was performed, as indicated by nearly 97 % of cases showing a "W" pattern in V1 before lead fixation. Only 88 % of patients exhibited a terminal r or R-wave in lead V1, demonstrating that conduction system capture can still be confirmed even in the absence of this specific ECG feature [3]. Our group favored stylet-driven leads, used in nearly 64 % of implants. However, the choice of tools and methods to assess reaching the LBB area (e.g., continuous pacing with the stylet connected to the PSA cable or rapid screwing eliciting "fixation beats") did not affect the final results.

Regarding periprocedural complications, the rate observed aligns with that seen in the MELOS and other trials [5,8]. Acute septal perforation was the most frequent complication, but it was resolved in all cases by repositioning the LBBAP lead without further clinical consequences. The incidence of LBBAP lead dislodgement was low, and even lower than that for atrial and conventional right ventricular myocardial pacing during follow-up (0.2 % vs. 1.3 %).

We were surprised to find that having a LBB block at implant independently predicted the success of LBBAP. To our knowledge, no similar reports exist, aside from observations that LBB patients receiving LBBAP as CRT had better responses compared to conventional biventricular pacing [10,24]. One hypothesis is that assessing procedural success is easier when full correction of LBB is observed in real-time during lead placement, or that implanters are more motivated to achieve QRS narrowing in heart failure patients, being less prone to accept sub-optimal results. This topic warrants dedicated retrospective and prospective trials to confirm the role of pre-implant LBB and improve patient selection.

The electrical parameters of LBBAP lead were excellent, both at implant and follow-up, with only 1.3 % incidence of loss of CSP during follow-up. This allows activation of algorithms for automated threshold evaluation, output management, and sensing assessment, providing high-quality remote monitoring of these devices [25,26].

4.1. Study limitations

A limitation of this study is the short-term follow-up. Nonetheless, the focus of our report was to describe the acute success and short-term complication rates in a heterogeneous, nationwide, real-world setting. Future data analyses through the C-SING network will help clarify whether LBBAP fulfills its long-term promises. Additionally, as this was an observational study that included only patients who underwent attempted LBBAP, we cannot exclude the risk of selection bias, nor can we directly compare outcomes with standard myocardial pacing or CRT procedures performed at the enrolling centers. Further research on recruitment policies for LBBAP across operators and centers would be valuable, while comparisons with alternative pacing strategies may be better explored through randomized trials targeting specific patient subgroups.

5. Conclusions

The C-SING, one of the largest available, nationwide multicenter study, demonstrated that LBBAP is routinely adopted both for bradycardia pacing and for treating and preventing heart failure. This technique is associated with high procedural success rates and acceptable complication rates, even when performed by less experienced operators. Experience with 50 procedures was associated with reduced fluoroscopy time and a lower risk of LBBAP lead implantation failure. The electrical parameters of LBBAP were very satisfactory and remained stable during the follow-up period, with a low incidence of loss of CSP capture. These findings underscore the feasibility and safety of LBBAP, highlighting its potential for broader clinical application and the importance of continuous training and standardized procedural guidelines.

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CRediT authorship contribution statement

Gabriele Dell'Era: Writing – original draft, Validation, Methodology, Investigation, Data curation, Conceptualization. **Pietro Palmisano:** Writing – review & editing, Investigation. **Matteo Bertini:** Writing – review & editing, Investigation. **Massimo Magnano:** Writing – review & editing, Investigation. **Matteo Baroni:** Writing – review & editing, Investigation. **Mario Volpicelli:** Writing – review & editing, Investigation. **Gianluca Mirizzi:** Writing – review & editing, Investigation. **Paolo Donateo:** Writing – review & editing, Investigation. **Luca De Mattia:** Writing – review & editing, Investigation. **Alessandro Paoletti Perini:** Writing – review & editing, Investigation. **Giovanni Rovaris:** Writing – review & editing, Investigation. **Francesco Solimene:** Writing – review & editing, Investigation. **Antonio Rapacciuolo:** Writing – review & editing, Investigation. **Francesco Raffaele Spera:** Writing – review & editing, Investigation. **Luca Poggio:** Writing – review & editing, Investigation. **Bruna Catuzzo:** Writing – review & editing, Investigation. **Enrico Boggio:** Writing – review & editing, Investigation. **Leonardo Marinaccio:** Writing – review & editing, Investigation. **Carlo Bonanno:** Writing – review & editing, Investigation. **Giacomo Mugnai:** Writing – review & editing, Investigation. **Donatella Ruggiero:** Writing – review & editing, Investigation. **Riccardo Sacchi:** Writing – review & editing, Investigation. **Alessandra Tordini:** Writing – review & editing, Investigation. **Gianni Pastore:** Writing – review & editing, Investigation. **Aldo Coppolino:** Writing – review & editing, Investigation. **Massimo Vito Tritto:** Writing – review & editing, Investigation. **Giuseppe Campisi:** Writing – review & editing, Investigation. **Gennaro Miracapillo:** Writing – review & editing, Investigation. **Paola Napoli:** Writing – review & editing, Software, Methodology, Formal analysis. **Daniele Giacopelli:** Writing – review & editing, Software, Methodology, Formal analysis. **Giuseppe Patti:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

Conflict of interest: Gabriele Dell'Era received fees for lectures and proctorship on conduction system pacing by Abbott, Biotronik and Boston Scientific; Matteo Bertini received small fees for lectures by Abbott, Biotronik, Boston, Microport and proctorship on conduction system pacing by Biotronik and Boston Scientific; Matteo Baroni received fees for lectures and proctorship on conduction system pacing by Abbott, Biotronik and Medtronic; Luca Poggio received fees for lectures and proctorship on conduction system pacing by Biotronik and Boston Scientific; Leonardo Marinaccio received fees for lectures and proctorship on conduction system pacing by Abbott, Biotronik, Boston Scientific and Medtronic; Paola Napoli and Daniele Giacopelli are employees of Biotronik. No other conflicts of interest to disclose.

Data availability statement

The data underlying this article will be shared on reasonable request to the corresponding author.

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Appendix A. Supplementary data

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