Learning curve and initial experience for left bundle branch area pacing with standard stylet-driven pacing leads: comparison with conventional right ventricular pacing

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Abstract

Introduction: His bundle pacing (HBP) was developed as a physiological conduction system pacing to complement the problem of conventional right ventricular pacing (RVP) related to dyssynchrony. Recently, left bundle branch area pacing (LBBAP), which overcomes the shortcomings of HBP, has been implemented. Most researches on initial experiences with LBBAP have reported that it was achieved through a lumen-less pacing lead (LLL) with a fixed helix design; however, there are situations in which LLL cannot be used. The purpose of present research is to evaluate the initial experience and learning curve of LBBAP using a standard stylet-driven lead with an extendable helix design. **Methods:** 265 patients who underwent LBBAP or conventional RVP performed by operators without previous LBBAP experience at Yonsei University Severance Hospital in Korea between December 2020 and October 2021 were enrolled. LBBAP was performed using a stylet-driven pacing lead with an extendable helix. The learning curve was evaluated by analyzing fluoroscopy and procedure times. **Results:** LBBAP was successful in 65 of 69 (94.2%) patients during the observation period. In 65 patients who underwent LBBAP, mean fluoroscopy and procedural times were 17.1 $\pm$ 17.2 minutes and 64.2 $\pm$ 33.5 minutes, respectively. The learning curve for achieving LBBAP plateaued after the 24th case, with a gradually shortened in procedure time. **Conclusion:** During the initial experience with LBBAP, fluoroscopy and procedural times improved with increasing operator experience. For operators who were experienced in cardiac pacemaker implantation, the steepest part of the learning curve was over the first 20-25 cases.

1. Introduction

Conventional right ventricular pacing (RVP) can cause electrical and mechanical dyssynchrony and is associated with increased risks of cardiac remodeling, pacemaker-induced cardiomyopathy, heart failure, and mortality.[1, 2]These deleterious effects have driven the search for alternative pacing sites. Conduction system pacing (CSP) is one such alternative that aims to directly activate the His-Purkinje conduction system thereby preserving synchronous ventricular activation and is thus deemed to be a more physiological alternative to conventional RVP.

Left bundle branch area pacing (LBBAP), proposed by Huang et al. in 2017,[3] has emerged as a new physiological conduction system modality that has a lower, more stable threshold and achieves a paced QRS duration similar to that of His bundle pacing (HBP).[4] LBBAP presents a simpler implantation technique, shorter fluoroscopy duration, and a procedure time with a steeper learning curve compared to HBP; thus, LBBAP is currently widely used as an alternative for CSP and considered the first strategy for patients in whom a high burden of ventricular pacing is anticipated.[5, 6]

In most cases, LBBAP has been performed exclusively using a lumen-less lead (LLL) with a fixed helix design (SelectSecure 3830 pacing lead, Medtronic Inc., Dublin, Ireland) and a pre-shaped sheath dedicated to this lead (C315His, Medtronic Inc.),[3, 7] both of which are unavailable in some centers and countries. Meanwhile, De Pooter et al. reported their early experience with LBBAP using a standard stylet-driven lead (SDL) in 20 cases, and the initial results showed feasibility and safety.[8] However, most researches have reported initial experience with LBBAP, and only few studies have focused on the learning curves for LBBAP. Moreover, no data exists on the learning curve for LBBAP with SDL. In this study, we aimed to evaluate the success rate, fluoroscopy and procedure time, lead and electrocardiography (ECG) parameters, and learning curve of LBBAP using SDL, and to compare these parameters with those of conventional RVP.

2. Methods

2.1 Study population

This retrospective observational study enrolled patients who underwent conventional RVP (n=200) or LBBAP (n=65) performed by operators without previous LBBAP experience between December 2020 and October 2021 at Yonsei University Severance Hospital in the Republic of Korea. All patients who required ventricular lead implantation during this period were included. For the learning curve analysis, patients who underwent dual-chamber pacemaker implantation by a single experienced operator were divided into a group that underwent conventional RVP (n=65) and a group that underwent LBBAP (n=50) (Figure 1). This study was followed the ethical rules of the Declaration of Helsinki (2013) of the World Medical Association, and approved by the Institutional Review Board of Yonsei University Health System. Following strict confidentiality guidelines, personally identifiable information were removed after the database was created and therefore exempt from prior consent requirements.

2.2 LBBAP procedural technique

All procedures, including conventional RVP and LBBAP, were performed by operators without previous LBBAP experience. LBBAP was performed with a 5.6Fr SDL with an extendable helix (Solia S60, Biotronik SE & Co KG, Berlin, Germany) delivered through a pre-shaped sheath (Selectra 3D, Biotronik). The lead was prepared as described previously by De Pooter et al.[8] Briefly, it was prepared by exposing the extendable screw by turning the outer pin 10 to 12 times clockwise, followed by five additional clockwise turns of the outer pin using the standard stylet guide tool delivered with the lead to avoid partial unwinding of the extendable helix (Supplementary Figure S1). We positioned a combined His/right ventricle (RV) catheter for ventricular backup pacing and His potential mapping as a landmark. The lead tip was placed at 1.5-2 cm toward the RV apex from the His area in the right anterior oblique view and perpendicular to the septum in the left anterior oblique view, as described in previous studies (Supplementary Figure S2 a).[3, 9] If His potential was not visible, we used the method similar to the simplified nine-partition method, which was also introduced in a previous study (Supplementary Figure S2 b).[10] Surface ECGs (12-lead) and intracardiac electrograms were continuously monitored using an electrophysiology recording system. Paced QRS morphology and unipolar pacing impedance were monitored. Left bundle branch (LBB) capture was confirmed using published criteria.[3, 11] Before lead penetration, the stylet was fully advanced to the pacing lead tip. For lead penetration, we advanced the pacing lead by fast rotation of the whole lead body 5-10 times to overcome septal resistance. Subsequently, pacing V1 morphology was checked whenever it was rotated one or two times.[8]When pacing the right side of the interventricular septum initially, the QRS of V1 showed the LBB block (LBBB) pattern. As the pacing lead penetrated the septum, the QRS of V1 gradually changed to the right bundle branch block (RBBB) pattern, and the pacing site was judged to be the LBB. At this point, a fast peak left ventricular activation time (LVAT) in leads V5 to V6 of approximately 75-80 ms was noted, which reflects the LBBAP. The LBB potential was recorded when the pacing lead was near or at the LBB.

2.3 Definition of LBBAP and LBBP

If the RBBB pattern in V1 was observed during unipolar pacing, it was considered a success for LBBAP regardless of the evidence of LBB capture. Therefore, the LBBAP includes deep septal pacing, nonselective LBB pacing (LBBP), and selective LBBP. To determine successful LBB capture, we followed and revised the definition of procedural success of LBB capture that was used in previous studies by Vijayaraman et al.[12] and

Wu et al.[13] If the RBBB configuration was seen in V1 during the unipolar pacing in addition to one or more of the following findings, the success of LBBP was confirmed: 1) Abrupt shortening of Stim-LVAT (stimulus to peak of the R wave in V6) of >10ms during increasing output; 2) Short and constant stim-LVAT and the shortest stim-LVAT <75ms in non-LBBB and <85ms in LBBB; 3) Programmed stimulation by pacing lead changes QRS morphology from nonselective LBB to LV septal capture; 4) LBB potential (LBB-V interval of 15 to 35ms); and 5) Transition from nonselective LBB capture to selective LBB capture at near threshold outputs. If LBB capture could not be demonstrated, further advancement of the lead tip was guided by monitoring the unipolar pacing impedance and/or observation of the fixation beat. Examples of intracardiac electrograms obtained during the LBBAP procedure are presented in Supplementary Figure S3.

2.4 Statistical analysis

Descriptive statistics were used to organize and interpret patients' baseline characteristics and comorbidities. Categorical variables are reported as frequencies (percentages), and continuous variables are reported as mean ± standard deviation or median (interquartile range). Categorical variables were compared using Fisher's exact test or Pearson's chi-square test, whereas continuous variables were compared using Student's t-test and Wilcoxon's rank-sum test.

The fluoroscopy and procedure times were modeled as cubic spline functions. The slope was calculated by differentiating the cubic spline curve with respect to the procedure time. A linear regression analysis was performed to confirm that the decrease in fluoroscopy and procedural time, followed by an increase in experience, was significant or not.

All tests were two-tailed with values of $p < 0.05$ considered as significant. Statistical analyses were performed using R programming version 4.0.3 (The R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1 Baseline characteristics

A total of 200 patients who underwent conventional RVP (mean age 70.47 ± 12.01 years, 49.5% female) and 50 patients who underwent LBBAP (mean age 68.75 ± 14.94 years, 50.8% female) were included in this study. A comparison of baseline characteristics among the groups is summarized in Table 1.

The distribution of pacing indications was as follows: In the conventional RVP group, sick sinus syndrome was the most common indication (54.0%), followed by atrioventricular (AV) block (46.0%). In the LBBAP group, AV block was more frequent (81.5%) than sick sinus syndrome (18.5%). The QRS duration was more likely to be narrow in the conventional RVP group (62.0%) than in the LBBAP group (40.0%).

3.2 LBBAP characteristics and pacing parameters

The electrophysiological characteristics and pacing parameters of LBBAP are shown in Supplementary Table 1. The LBB capture threshold at implant was 0.9±1.1 mV, sensed R wave amplitude was 10.6±5.0 mv, and pacing impedance was 675.1±100.6 Ω. After pacemaker implantation, QRS duration was significantly decreased (128.6±30.2 ms to 120.5±20.1 ms, p=0.04) in the total LBBAP population.

3.3 LBBAP with SDL procedure-related outcomes

LBBAP was successful in 65 of 69 (94.2%) patients, while 200 underwent conventional RVP. Four patients in whom LBBAP failed, conversion to conventional RVP was done and these patients were excluded from this study population. The procedural outcomes according to the increase in experience were as follows: Up to the 25th case, until the plateau phase of the procedure, the time was defined as the early period, and after the plateau phase, it was further divided into a middle period and a late period (divided by 20 cases each). The success rates of the procedures in each period were 89.3%, 95.2%, and 100%, respectively (Table 2, Supplementary Figure S4). The number of screw attempts did not significantly decrease as the number of cases increased, but the number of sheath change (0.36 ± 0.70, 0.20 ± 0.52, P <0.05) significantly decreased as the number of cases increased.

There were three cases of major complications during the early and middle period, of which there was one hematoma requiring prolonged hospitalization, and two ventricular lead dislodgements occurring 1 day and 3 months after the procedure, respectively. Of the two dislodgement cases, one patient required ventricular lead revision and LBBAP was achieved again, and one case did not require revision because of its stable parameters with a ventricular lead in the RV inferior wall.

3.4 Learning curve in LBBAP with SDL procedures

To eliminate bias, analyses were performed on patients who underwent the same procedure by a single operator. In 65 patients who underwent conventional RVP, the mean fluoroscopy and procedural time were 5.6 ± 3.2 and 42.7 ± 15.5 minutes, respectively. Of the 50 patients who underwent LBBAP, the mean fluoroscopy and procedural times across all procedures were 15.1 ± 13.5 and 59.9 ± 24.8 minutes, respectively (Table 3). The fluoroscopy and procedure times for LBBAP were modeled as cubic spline functions, and the curve showed that both fluoroscopy and procedure time decreased with operator experience (Figure 2). To confirm the plateau phase of the procedure time, we differentiated the cubic spline curve with respect to the procedure time to find the point where the slope was zero (Supplementary Figure S5). In this study, the plateau phase of the procedure time for LBBAP began in the 24th case. We compared the difference in procedure time between conventional RVP and LBBAP in the two phases based on the 24$^{\text{th}}$ case where the treatment time plateau was performed (before plateau phase [?] 24$^{\text{th}}$ case, and after plateau phase > 24$^{\text{th}}$ case) (Figure 3). After the plateau was achieved during the LBBAP procedure, the median time difference between the two methods was confirmed to be 16 min (Table 3).

5. Discussion

The major findings of this study were as follows: 1) LBB capture threshold and pacing impedance were stable in the LBBAP population; 2) after LBBAP, QRS duration was significantly decreased; 3) learning curves for LBBAP procedures continued to improve with increasing operator experience; and 4) higher success rates and lower complication rates were achieved as experience increased.

Although HBP, which was first introduced by Deshmukh et al. in 2000,[14] has been suggested as the ideal approach for physiological ventricular activation,[15] wider clinical application of HBP is limited by several problems, including technical difficulties in identifying the precise location, variable success rates, and potential risk of premature battery depletion and lead revisions due to progressive increases in capture thresholds.[15, 16]

In this regard, LBBAP, which has a stable and lower capture threshold and a similarly paced QRS duration to HBP, has emerged as a new physiological conduction system modality.[4, 5, 17]LBBAP presents a simpler implant technique, shorter fluoroscopy, and shorter procedure time with a steeper learning curve compared to HBP; thus, LBBAP is now widely used as an alternative for conventional SP and considered as the first strategy for patients in whom a high burden of ventricular pacing is anticipated.[5, 17] However, LBBAP has not yet reached widespread clinical use, and the main obstacle to widespread use is the limited array of available tools for LBBAP implantation. Although most cases of LBBAP have been exclusively performed using LLL with a fixed helix design and a pre-shaped sheath dedicated to this lead, LLL is not available to all manufacturers and implanters; thus there is a limited ability to offer LBBAP to all patients. Therefore, the ability to perform LBBAP with SDLs seems to encourage more implanters to attempt the LBBAP.

In this study, the plateau phase of the procedure time for LBBAP with SDL began from the 24th case, which is shorter than the previously reported learning curves (30–50 cases) of HBP and even LBBAP using LLL.[18-20] In addition to the known advantages of the shorter learning curve of LBBAP compared to those of HBP, familiarity with SDL also contributed to a shorter learning curve than that of HBP.

These data are encouraging for centers considering the implementation of an LBBAP procedure, suggesting improved procedural results and procedural time with increased operator experience, which may lead to a more challenging procedure.

Study limitations

This study had some limitations. First, this was a retrospective, observational, non-randomized study. Second, we purposely analyzed the experience of a single operator with the aim of reducing bias, but we believe that the results are broadly applicable. Comparing the experiences of multiple physicians in multiple centers would have better ensured its generalizability.

Conclusion

In conclusion, during the initial experience of LBBAP with SDL, procedural and fluoroscopy times continued to improve with operator experience. For physicians who are experienced in cardiovascular implantable electronic device implantation and without previous LBBAP experience, the steepest part of the learning curve was over the first 20-25 cases.

Disclosures

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Data availability Statement:

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Conflict of Interest:

The authors have declared that there are no competing interests.

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Figure Legends

Figure 1. Flowchart of the enrolment and analysis of procedure time and fluoroscopy time assessment

Figure 2. Learning curve metrics for left bundle branch area pacing using a standard stylet-driven lead.

A. The relationship between fluoroscopy time and center experience

B. The relationship between procedure time and center experience

Figure 3. Time required left bundle branch area pacing using a standard stylet-driven lead when compared to conventional right ventricular pacing between early stage and late stage.

The early stage is first case to the 24th case, when the plateau phase begins at the procedure time, and the late stage is from the 25th case, after the plateau phase has arrived at the procedure time.

Fluoroscopy time (A) and procedure time (B) separated by experience group are presented demonstrating a significant improvement in time across the groups (both $P<0.01$).

Figure 1

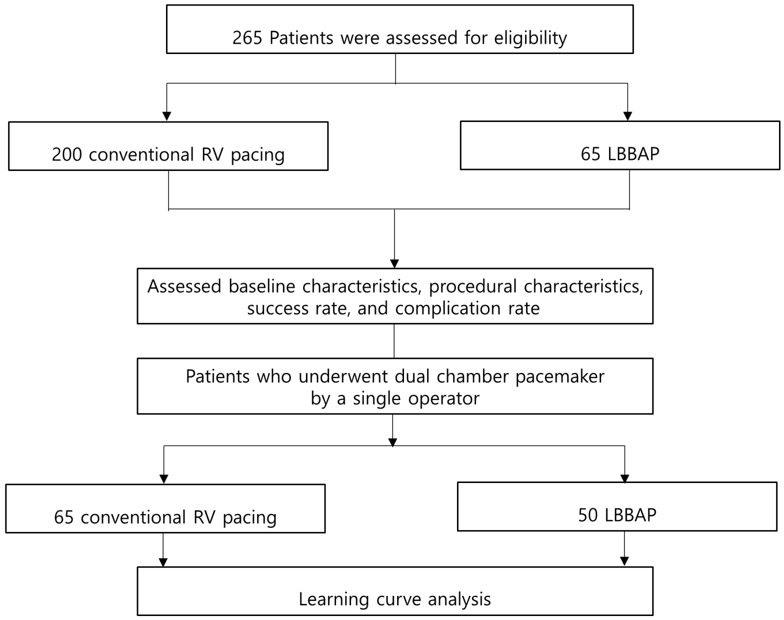


Figure 2

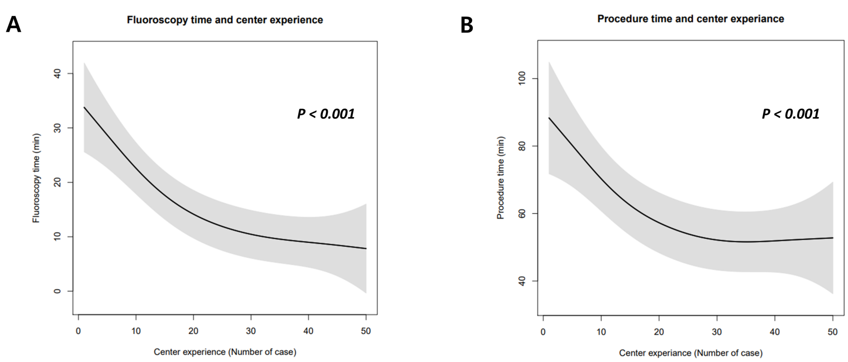
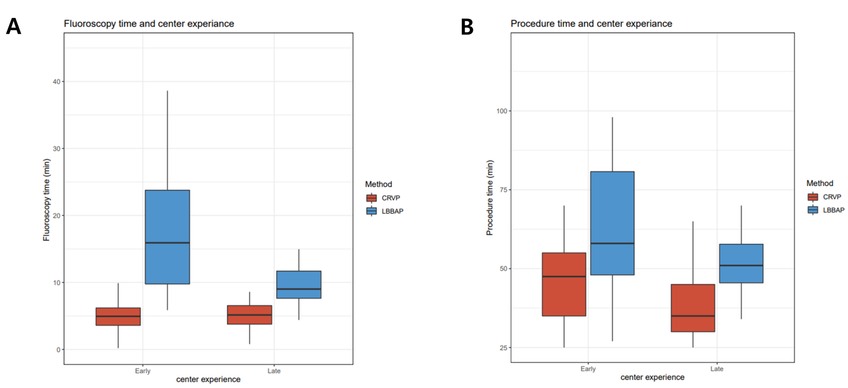


Figure 3



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