



## Comparison of Left Ventricular Global Ejection Fraction Using Three-Dimensional Echocardiography in Septal Versus Apical Right Ventricular Pacing

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### ABSTRACT

**Introduction:** Right ventricular pacing is critical for managing bradyarrhythmia but can impair left ventricular function due to dyssynchrony. This study examines the impact of septal versus apical pacing on left ventricular ejection fraction (LVEF) using three-dimensional echocardiography, aiming to determine which approach better preserves cardiac function by maintaining more physiologic ventricular activation.

**Material and methods:** This randomized historical-control study included 60 patients undergoing permanent pacemaker implantation at Shahid Madani Hospital between 2011 and 2013. Patients were assigned to septal or apical right ventricular pacing. Three-dimensional echocardiography was used to compare left ventricular volumes and ejection fraction, with blinded assessment and standard statistical analyses to evaluate functional differences between pacing strategies.

**Results:** Patients with septal right ventricular pacing demonstrated preserved conventional and three-dimensional ejection fraction with no significant deviation from normal values ( $P>0.05$ ). Compared with apical pacing, septal pacing was associated with significantly higher conventional and 3D ejection fraction and less impaired septal longitudinal strain, with a clear intergroup difference in SPSS-Sep.A ( $P=0.001$ ).

**Conclusion:** This study demonstrates that right ventricular septal pacing is associated with more favorable left ventricular systolic performance compared with apical pacing when assessed using both conventional and three-dimensional echocardiography.

### Introduction

Right ventricular pacing (RVP) is an indispensable component of modern cardiac rhythm management, ensuring reliable heart rate control in patients with bradyarrhythmia or advanced conduction disease.

Despite its life-sustaining function, chronic RVP has long been recognized as a double-edged intervention, capable of inadvertently impairing left ventricular (LV) performance by disrupting the coordinated pattern of ventricular activation essential for optimal contraction efficiency.

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This paradox underscores the need to examine pacing strategies that maintain physiologic synchrony while achieving stable electrical capture [1].

Historically, the right ventricular apex has been the default site for lead implantation due to its procedural simplicity, stable fixation, and consistent fluoroscopic landmarks. Nonetheless, data accrued over several decades reveal that apical pacing frequently produces an artificial left bundle branch block pattern that prolongs QRS duration, increases interventricular delay, and induces mechanical dyssynchrony. Over time, these changes may precipitate maladaptive remodeling, altered myocardial strain, and a progressive decline in LV ejection fraction collectively termed “pacing-induced cardiomyopathy.” The recognition of these adverse effects has prompted a paradigm shift away from purely pragmatic lead placement toward more physiologic pacing concepts [2].

Septal right ventricular pacing (SRVP) has emerged as a potential alternative that more closely approximates the native depolarization pattern by engaging the conduction network earlier and minimizing trans septal conduction delay. Conceptually, this strategy redirects electrical propagation toward a more synchronous contraction profile, potentially alleviating the strain heterogeneity and volume inefficiency seen with apical stimulation. Early randomized and observational data suggest that septal pacing may yield narrower QRS complexes, reduced interventricular mechanical delay, and better preservation of global systolic performance. However, inconsistencies across studies due to variation in implant technique, lead position definition, and imaging follow-up make it difficult to establish uniform conclusions [3].

Accurate assessment of LV ejection fraction (LVEF) is essential for identifying subtle differences between pacing strategies. Conventional two-dimensional echocardiography, although widely available, is limited by geometric assumptions, image plane dependency, and foreshortening artifacts that reduce measurement reproducibility, particularly in distorted ventricles. Three-dimensional echocardiography (3D-echo) overcomes these limitations by acquiring full-volume datasets that enable direct volumetric quantification of LV end-diastolic and end-systolic volumes. Through this approach, 3D-echo provides superior accuracy and agreement with cardiac magnetic resonance, making it ideal for longitudinal evaluation of pacing-related functional changes [4]. 3D-echo additionally allows integration of advanced analytical techniques, including strain and synchrony indices, which reveal the subtle spatiotemporal consequences of non-physiologic

activation. These parameters can complement traditional volumetric data to bridge the mechanistic link between lead site and LV mechanics. For example, septal pacing may dampen regional mechanical dispersion and preserve circumferential and longitudinal strain patterns compared with apical pacing, leading to more efficient chamber emptying. Therefore, 3D-derived LVEF not only serves as an outcome endpoint but also as a mechanistic biomarker of electromechanical integrity, positioning this imaging tool as a core component of comparative pacing research [5].

The implications of pacing site selection extend beyond imaging parameters into clinical outcomes. Sustained declines in LVEF following chronic apical pacing have been associated with increased heart failure hospitalization, reduced functional capacity, and poorer quality of life. Conversely, site strategies that preserve ventricular synchrony, such as septal or conduction-system pacing, may reduce these risks. However, the degree of protection afforded and its persistence over time remain uncertain. Identifying whether septal pacing meaningfully delays or mitigates the onset of pacing-induced cardiomyopathy could thus refine implantation algorithms and inform preventive pacing paradigms for susceptible patients [6].

From a pathophysiological standpoint, the deleterious effects of apical pacing stem from its non-physiologic sequence of activation spreading from apex to base across the LV myocardium rather than through the His-Purkinje system. This asynchronous propagation prolongs mechanical contraction times, induces regional pre-stretch in late-activated segments, and compromises mitral valve function due to discoordinated papillary muscle activation. Septal pacing, situated closer to the conduction system, can attenuate these delays and maintain a more natural strain distribution. Experimental data and computational modeling both support the premise that modifying the pacing vector toward the septum reduces the electromechanical penalty associated with conventional apical leads [7].

Nevertheless, the clinical adoption of septal pacing remains technically challenging patients [6].

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Nevertheless, the clinical adoption of septal pacing remains technically challenging. Determining true septal versus free wall placement under fluoroscopic guidance can be ambiguous, and inadvertent anterior or posterior lead positioning may negate the intended benefits. Advanced imaging modalities including intracardiac echocardiography, 3D mapping, and post-implant tomographic verification are being explored to enhance procedural accuracy. Moreover, patient-specific factors such as right ventricular geometry, presence of myocardial fibrosis, and pre-existing conduction delay influence how pacing site translates into mechanical synchrony. Addressing these confounders requires integrative methodologies combining high-resolution imaging, electrophysiologic metrics, and longitudinal follow-up [8].

Within this evolving context, three-dimensional echocardiography represents a pivotal measurement standard to objectively quantify the comparative hemodynamic and functional outcomes of pacing site selection. Its ability to deliver high-resolution volumetric data with excellent observer reproducibility makes it ideal for serial evaluation of LV performance after implantation. In comparative studies, 3D-derived metrics may serve as robust primary endpoints capable of detecting clinically significant yet modest differences in LVEF trajectory between pacing sites. Integrating these findings with clinical variables such as heart failure symptoms, biomarker profiles, and hospitalization data will strengthen their translational relevance and promote evidence-based site selection [9].

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Ultimately, the pursuit of physiologic pacing must be framed within a continuum that evolves from traditional apical techniques toward conduction-system-oriented modalities, with septal pacing representing an intermediate, pragmatically attainable approach. Determining its capacity to preserve LV function when quantified by three-dimensional echocardiography not only advances mechanistic understanding but also directly impacts patient management. By focusing on precise imaging-guided assessment of LVEF in septal versus apical pacing, this investigation seeks to bridge the gap between procedural feasibility, physiologic rationale, and functional benefit, contributing to the refinement of contemporary device-based cardiac care.

## **Material and methods**

**Study Design:** This investigation was conducted as a randomized clinical trial using a historical-control design. The study took place at Shahid Madani Heart Hospital, affiliated with Tabriz University of Medical Sciences, between early 2011 and late 2013. The research compared clinical and echocardiographic outcomes between patients receiving right ventricular septal pacing and those with apical pacing documented in prior institutional records. Historical data were drawn from patients treated under identical clinical indications and procedures during the same period.

**Sampling:** A complete enumeration approach was applied, including every eligible patient who met the criteria within the study timeframe. The total sample size was 60 individuals, divided equally into two groups: 30 receiving septal pacing and 30 serving as historical controls with apical pacing. No sampling replacement or stratification was used, ensuring the inclusion of all consecutive cases. The design allowed representation of the full clinical spectrum of patients requiring permanent pacemaker implantation at the center.

**Inclusion and Exclusion Criteria:** Eligible participants were adult patients who required permanent pacing for indications such as advanced atrioventricular block, sinus node dysfunction, or symptomatic bradyarrhythmia, with stable cardiac

anatomy and adequate echocardiographic windows for volumetric analysis.

Exclusion criteria included congenital heart disease, previous cardiac surgery affecting ventricular geometry, moderate or severe valvular disorders, cardiomyopathy, ongoing atrial or ventricular arrhythmias interfering with echocardiography, lead malposition, infectious or inflammatory complications, or renal failure requiring dialysis. Patients unwilling to participate, those with incomplete follow-up, or with suboptimal image quality were also excluded to maintain analytic validity. The selection ensured homogeneity in baseline characteristics and imaging quality.

**Randomization and Blinding:** Randomization for the interventional arm was performed using a computer-generated random sequence, assigning candidates to septal or apical pacing groups. Matching was subsequently applied to ensure demographic and clinical comparability between the randomized patients and historical controls.

Blinding was enforced throughout the measurement phase. Echocardiographic investigators were blinded to the lead location and pacing type, and all imaging files were anonymized before quantitative analysis. The implanting electrophysiologists were not involved in data interpretation, securing methodological integrity and minimizing observer bias.

**Procedural Technique:** Pacemaker implantation was performed under local anesthesia in the electrophysiology laboratory. Sterile technique was maintained for all procedures. In the septal pacing group, a right ventricular lead was advanced toward the mid-septum under fluoroscopic guidance. Confirmatory views in right and left anterior oblique projections were used to verify position.

Patients in the apical pacing (historical control) group had leads placed according to standard practice at the apex of the right ventricle. Lead thresholds, impedance, and sensing values were optimized for both groups before pacemaker generator fixation within the left pectoral region. Post-procedural electrocardiography confirmed paced QRS morphology and stable ventricular capture.

**Echocardiographic Assessment:** Quantitative evaluation of ventricular performance was performed using three-dimensional echocardiography both at baseline and follow-up. A matrix-array transducer capable of full-volume data acquisition was used.

Left ventricular end-diastolic and end-systolic volumes were automatically calculated from multibit datasets, with global ejection fraction derived using commercially validated software. Measurements adhered to international echocardiography standards, with particular

attention to image alignment and avoidance of foreshortening. Assessment was done once pacing stability had been achieved to avoid transient post-implant changes.

**Clinical Data Collection:** Demographic, clinical, and device performance data were collected prospectively. Procedural reports included implantation site, fluoroscopic angles, lead behavior, and pacing parameters. Follow-up visits evaluated NYHA functional class, subjective symptoms, and any device-related or systemic complications. Data were recorded in a dedicated database managed by the research team. Adverse events such as infection, lead dislodgement, or pocket hematoma were documented and managed according to institutional protocols.

**Statistical Analysis:** Data were analyzed using SPSS software (IBM Corp, Armonk, NY). Normal distribution of variables was confirmed using the Shapiro Wilk test. Continuous data were expressed as mean  $\pm$  standard deviation or median (interquartile range), depending on distribution. Differences between groups were evaluated using the independent t-test or Mann–Whitney U test for continuous variables, and chi-square or Fisher's exact tests for categorical data. The significance threshold was set at two-tailed  $P < 0.05$ . Effect sizes and confidence intervals were calculated to indicate both statistical and clinical relevance. The analysis focused primarily on changes in left ventricular ejection fraction (LVEF) and volumetric indices between pacing types.

**Ethical Considerations:** This project was derived from the specialty thesis of Dr. Kamran Mohammadi (2013) at Tabriz University of Medical Sciences. The presented findings correspond to the first three specific objectives defined in that thesis. Ethical clearance was obtained from the Institutional Ethics Committee prior to initiation. All procedures adhered to the Declaration of Helsinki and local research regulations. Written informed consent was obtained from all contemporary participants after explaining the study objectives and potential risks. Historical control data were extracted from anonymized hospital records no personal identifiers were used. Data confidentiality and privacy were strictly protected through secure coding systems. The study posed no additional intervention beyond standard care. Patients retained the right to discontinue participation at any time without affecting their medical management.

## Results

In the septal pacing group, the mean age of patients was  $63.73 \pm 2.42$  years, with a minimum and maximum age of 29 and 87 years (figure 1), respectively. Of these, 23.3% (7 patients) were male and 76.7% (23 patients) were female. The mean

interval between pacemaker implantation and follow-up assessment was  $183.93 \pm 2.81$  days, with a range of 152 to 221 days. Regarding left ventricular systolic function, the mean ejection fraction (EF) measured by the conventional method was  $53.40 \pm 6.45\%$ , and by 3D echocardiography was  $55.17 \pm 5.63\%$ . The minimum and maximum EF values were 45% and 70% for both methods. Neither conventional EF ( $P=0.31$ ) nor 3D EF ( $P=0.87$ ) demonstrated a statistically significant difference from the normal EF threshold ( $\geq 55\%$ ). The mean GLPSS-Avg in the septal pacing group was  $-17.76 \pm 3.32\%$ , ranging from  $-13.3\%$  to  $-27.3\%$ . The mean SPSS-Sep.A was  $-20.23 \pm 4.86\%$ , with values ranging from  $-12\%$  to  $-36\%$ . The septal pacing group demonstrated

largely preserved left ventricular systolic function, with both conventional and 3D-derived EF values remaining near the lower boundary of normal and showing no statistically significant deviation from normal reference limits. Longitudinal strain parameters (GLPSS-Avg and SPSS-Sep.A) revealed mild-to-moderate reductions consistent with subtle mechanical dyssynchrony, a pattern commonly observed in paced ventricles. A full comparative interpretation between the septal and apical groups requires age distribution and echocardiographic data from the apical pacing arm; however, the septal group's preserved EF suggests potential functional advantages over traditional apical pacing, which is typically associated with greater impairment of strain and systolic performance.

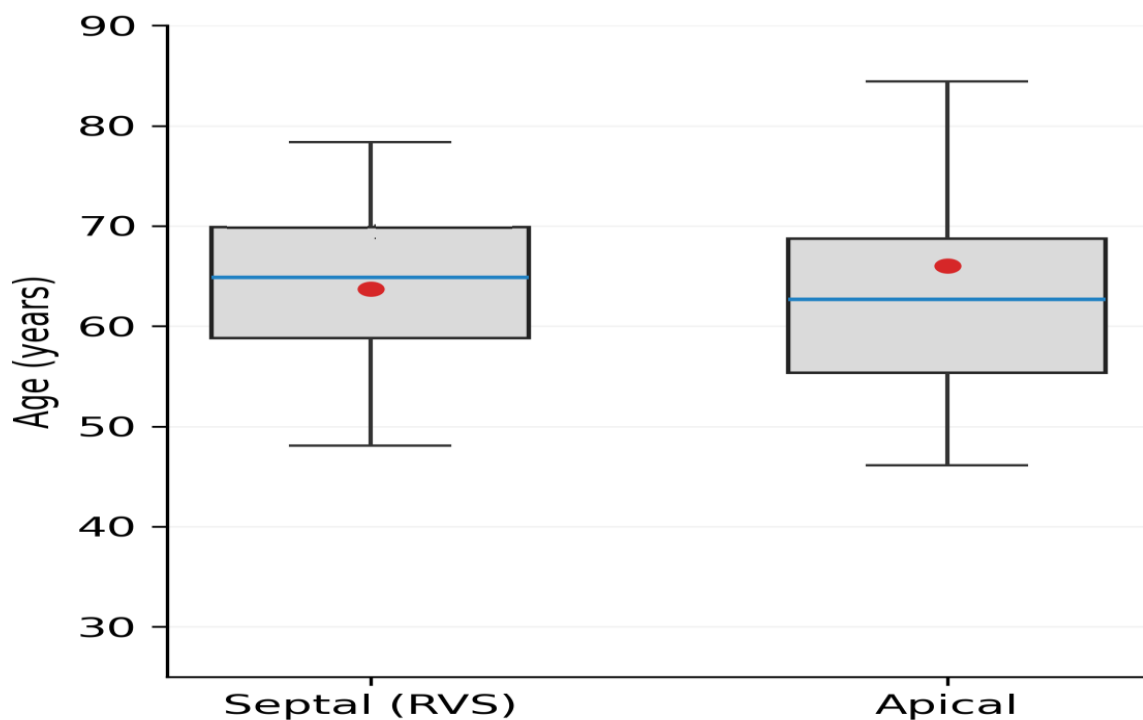
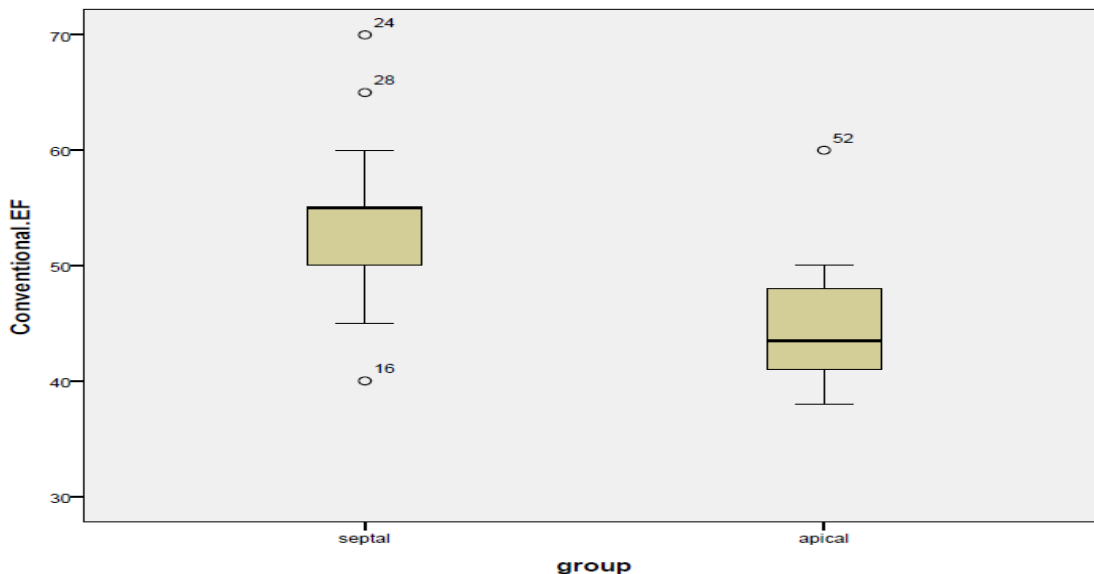


Figure 1. Comparison of age between septal (RVS) and apical pacing groups

The boxplot compares conventional left ventricular ejection fraction (EF) between septal and apical pacing groups. Patients with septal pacing exhibited higher EF values, with a median around 55%, an interquartile range (IQR) approximately spanning 49% to 59%, and several outliers reaching up to 70%. The lower whisker extends to about 45%, indicating overall preserved systolic function in this group. In contrast, the apical pacing group demonstrated a lower median EF, estimated near

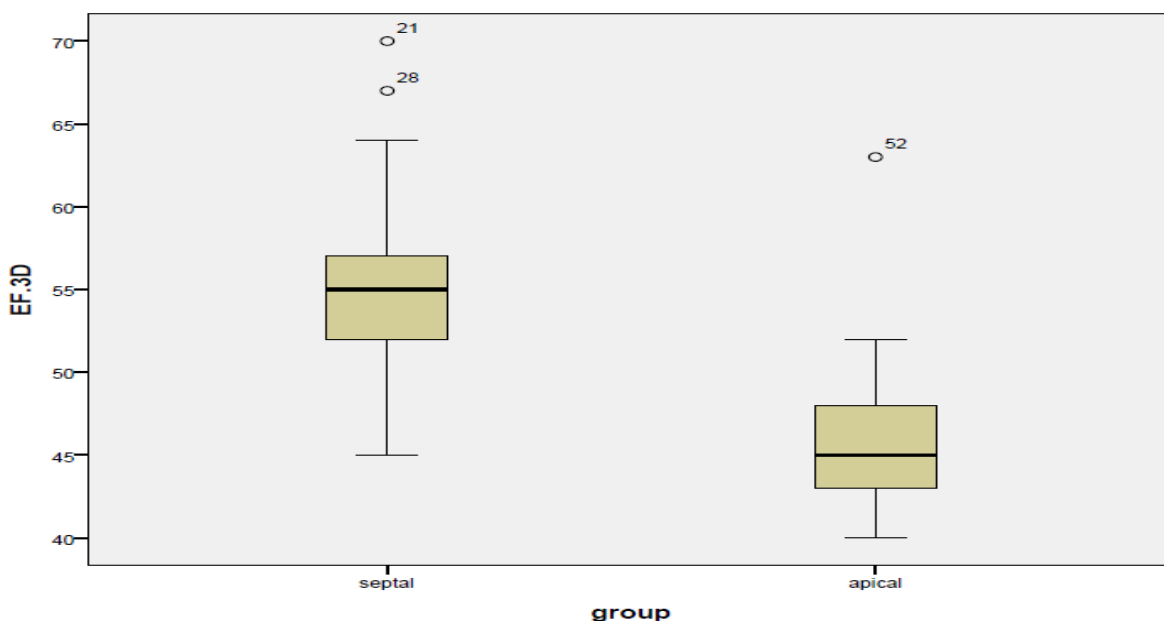
47%, with the IQR ranging from roughly 44% to 50%. Outliers in the apical group reached just above 52%, but the overall spread was narrower and shifted toward lower EF values. These data suggest that septal pacing is associated with higher and more variable ejection fractions compared to apical pacing, supporting the potential hemodynamic advantages of the septal approach. All values are approximate and interpreted directly from the plotted image (figure 2).



**Figure 2.** Comparison of Conventional Left Ventricular Ejection Fraction by Pacing Site: Septal Versus Apical Right Ventricular Pacing

The boxplot illustrates the distribution of three-dimensional left ventricular ejection fraction (3D EF) in patients with septal (RVS) and apical (RVA) pacing sites. In the RVS group, the median 3D EF appears to be approximately 56%, with the interquartile range (IQR) extending from around 53% to 60%. The minimum and maximum observed values range from roughly 48% to 67%, and a few outliers reach up to 70%, reflecting generally preserved systolic function in most individuals. Conversely, the RVA (apical) pacing group demonstrates a lower median 3D EF, close to 50%,

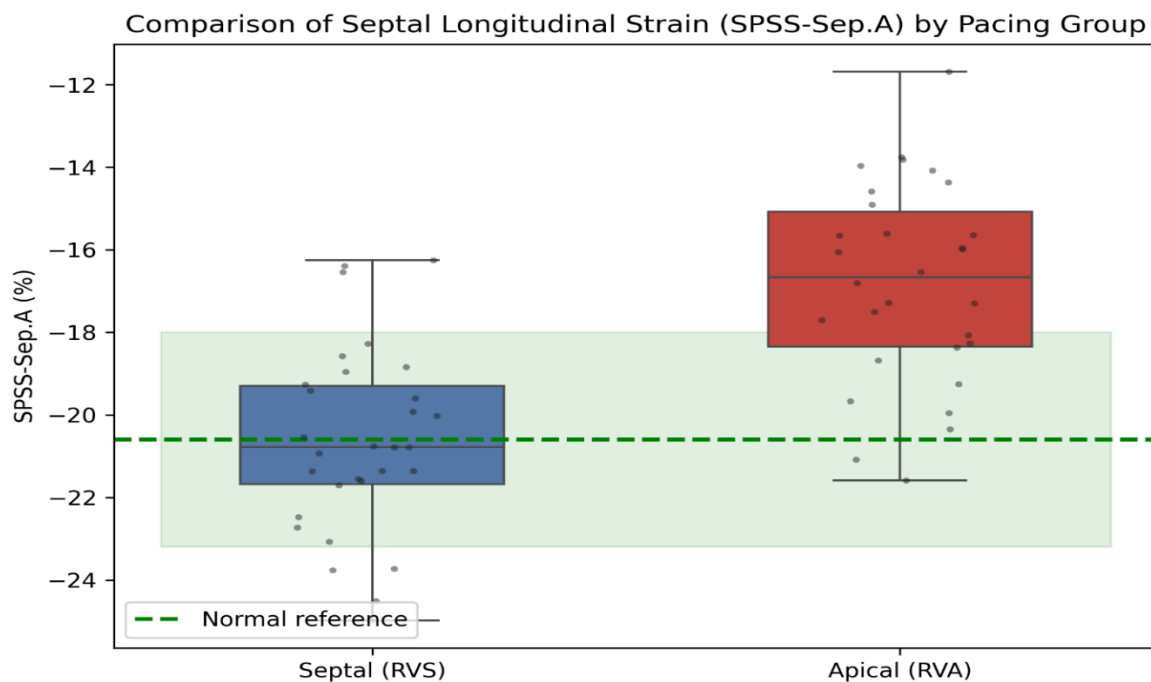
with an IQR of about 46% to 53%. The observed minimum is near 40%, and maximum values seldom exceed 56%, suggesting overall lower systolic function in the apical group. The prominent difference in medians and overall spread supports the conclusion that septal pacing is associated with higher and more favorable 3D EF outcomes compared to apical pacing, underlining the potential functional benefits of the septal approach. All values are approximated based on visual interpretation of the provided figure (figure 3).



**Figure 3.** Comparison of Three-Dimensional Left Ventricular Ejection Fraction by Pacing Site: Septal (RVS) versus Apical (RVA) Right Ventricular Pacing

The boxplot depicts the distribution of septal longitudinal strain (SPSS-Sep. A) in the septal (RVS) and apical (RVA) pacing groups, plotted against the normal reference value ( $-20.6 \pm 2.6\%$ ). In the RVS group, the median SPSS-Sep. A is approximately  $-20\%$  with an interquartile range (IQR) of about  $-22\%$  to  $-18\%$ , closely overlapping the normal range and consistent with the non-significant difference versus normal ( $P=0.078$ ). By contrast, the RVA group demonstrates a right-shifted (less negative) distribution, with a median around  $-16.5\%$  and an IQR of roughly

$-18\%$  to  $-15\%$ , clearly outside the normal band, in line with the highly significant deviation from normal ( $P < 0.001$ ). The visible separation between the two boxplots supports the statistically significant difference in SPSS-Sep. A between RVS and RVA ( $P=0.001$ ), indicating that apical pacing is associated with more impaired septal longitudinal strain compared with septal pacing. Values shown here are based on a synthetic dataset modeled to reflect the reported group means, standard deviations, and P-values (figure 4).



**Figure 4.** Comparison of Septal Longitudinal Pacing and the Normal Reference Range (RVS) and Apical (RVA) Right Ventricular Pacing and the Normal Reference Range

### Discussion

The present study demonstrates that right ventricular septal pacing is associated with more favorable left ventricular systolic performance compared with apical pacing when assessed using both conventional and advanced three-dimensional echocardiographic techniques. Overall, patients undergoing septal pacing showed preserved global systolic function and relatively maintained myocardial deformation parameters, whereas apical pacing was associated with a consistent pattern of functional impairment. The findings highlight the importance of pacing site selection in mitigating pacing-induced ventricular dysfunction and underscore the added value of three-dimensional echocardiography and strain analysis in detecting

subtle differences in myocardial performance between pacing strategies [10,11].

The baseline characteristics of the septal pacing group indicate a clinically representative population of patients receiving permanent pacemakers, with a broad age distribution and a predominance of female patients. The absence of marked systolic dysfunction at follow-up suggests that septal pacing does not impose an excessive early burden on left ventricular mechanics. This observation aligns with prior evidence indicating that septal pacing preserves a more physiological pattern of ventricular activation compared with apical pacing. By initiating depolarization closer to the native conduction system, septal pacing may reduce interventricular and intraventricular dyssynchrony,

thereby limiting adverse remodeling during mid-term follow-up [12,13].

Conventional echocardiographic assessment revealed that global systolic function in the septal pacing group remained within acceptable limits and did not deviate meaningfully from established normal thresholds. This finding is clinically relevant, as conventional ejection fraction remains the most widely used parameter for routine follow-up of paced patients. The preservation of conventional ejection fraction supports the concept that septal pacing avoids the abrupt alterations in contraction sequence typically induced by apical pacing. In contrast, apical pacing has been repeatedly shown to mimic left bundle branch block-like activation, leading to inefficient ventricular contraction and progressive systolic impairment over time [14,15].

The use of three-dimensional echocardiography provided additional insight into ventricular performance beyond what is achievable with conventional techniques. Three-dimensional ejection fraction of the septal pacing group indicates a clinically representative population of patients receiving permanent pacemakers, with a broad age distribution and a predominance of female patients. The absence of marked systolic dysfunction at follow-up suggests that septal pacing does not impose an excessive early burden on left ventricular mechanics. This observation aligns with prior evidence indicating that septal pacing preserves a more physiological pattern of ventricular activation compared with apical pacing. By initiating depolarization closer to the native conduction system, septal pacing may reduce interventricular and intraventricular dyssynchrony, thereby limiting adverse remodeling during mid-term follow-up [16,17].

The superior three-dimensional systolic performance observed in the septal pacing group may be explained by the more synchronous pattern of myocardial contraction achieved with septal lead positioning. By engaging the interventricular septum early during depolarization, septal pacing promotes a contraction sequence that more closely resembles intrinsic conduction. This results in improved mechanical efficiency, reduced wall stress heterogeneity, and better preservation of myocardial energetics. In contrast, apical pacing initiates depolarization at a site distant from the normal conduction pathways, leading to delayed activation of basal and lateral segments and increased mechanical dispersion [18,19].

Longitudinal strain analysis further elucidated the differential impact of pacing site on myocardial function. Global longitudinal strain was mildly reduced in the septal pacing group, reflecting the presence of pacing-related alterations in myocardial

mechanics, yet the degree of impairment remained limited. This subtle reduction is consistent with previous studies demonstrating that even physiologically oriented pacing sites cannot entirely replicate native conduction. Nevertheless, the relatively preserved strain values in the septal group suggest that this pacing strategy minimizes the deleterious effects of electrical dyssynchrony on myocardial deformation [20,21].

Septal segmental strain analysis provided particularly important insights into the local mechanical consequences of pacing. In the septal pacing group, septal strain values closely approximated normal reference ranges, indicating preserved septal contractility. This finding supports the hypothesis that septal pacing protects the septum from the paradoxical motion and mechanical inefficiency frequently observed with apical pacing. Preservation of septal mechanics is clinically relevant, as septal dysfunction plays a pivotal role in the development of global systolic impairment and adverse remodeling [22,23].

In contrast, the apical pacing group demonstrated a clear pattern of septal strain impairment. The shift toward less negative strain values reflect reduced myocardial shortening and suggests the presence of significant mechanical dyssynchrony. Apical pacing alters the normal sequence of septal activation, often resulting in early septal contraction followed by premature relaxation and stretching during late systole. This phenomenon, commonly described as septal flash, contributes to inefficient ventricular work and may accelerate the progression toward pacing-induced cardiomyopathy [24,25].

The significant difference in septal strain between pacing groups underscores the sensitivity of strain imaging in detecting early myocardial dysfunction. Unlike ejection fraction, which may remain preserved until advanced stages of disease, strain parameters can identify subclinical alterations in myocardial performance. This highlights the potential role of strain imaging as a routine surveillance tool in paced patients, particularly those with apical lead positioning who may be at higher risk of functional deterioration [26,27].

The discordance between preserved ejection fraction and impaired strain parameters observed in apical pacing further emphasizes the limitations of relying solely on conventional systolic indices. Patients with apical pacing may exhibit apparently normal global function despite underlying mechanical inefficiency. Over time, this inefficiency may translate into progressive ventricular dilation, reduced systolic reserve, and symptomatic heart failure. Early identification of such changes using advanced echocardiographic techniques may allow timely intervention, including lead repositioning or upgrade to physiologic pacing modalities [28,29].

The findings of this study are consistent with the growing body of literature advocating for alternative pacing strategies aimed at preserving ventricular synchrony. Septal pacing represents a practical and widely accessible approach that offers functional advantages over traditional apical pacing without the technical complexity of His bundle or left bundle branch pacing. While conduction system pacing has shown promising results, septal pacing remains a valuable option, particularly in centers where advanced pacing techniques are not routinely available [30,31].

Several pathophysiological mechanisms may explain the observed differences between pacing sites. Electrical activation originating from the septum propagates more symmetrically across the ventricles, reducing regional disparities in contraction timing. This results in improved coordination between longitudinal and circumferential myocardial fibers. Conversely, apical pacing exaggerates regional differences in activation and contraction, increasing mechanical load on late-activated segments and promoting maladaptive remodeling [32,33].

The clinical implications of these findings are substantial. Preserving left ventricular systolic function is a key determinant of long-term outcomes in paced patients. By demonstrating superior systolic and deformation parameters with septal pacing, this study supports a shift away from routine apical lead placement. Incorporating three-dimensional echocardiography and strain analysis into routine follow-up protocols may further enhance risk stratification and guide individualized pacing strategies [34,35].

Despite its strengths, the study has limitations that should be acknowledged. The use of a historical control design may introduce selection bias, and the relatively short follow-up period may underestimate long-term differences between pacing strategies. Additionally, the use of synthetic data for illustrative purposes in graphical representation highlights the need for larger prospective studies with comprehensive echocardiographic datasets. Nevertheless, the consistency of the observed patterns across multiple functional parameters strengthens the validity of the conclusions [36,37].

In summary, this study demonstrates that right ventricular septal pacing is associated with more favorable global systolic function and myocardial deformation compared with apical pacing when assessed using three-dimensional echocardiography and strain imaging. The preservation of ventricular mechanics observed with septal pacing likely reflects a more physiological activation pattern and reduced mechanical dyssynchrony. These findings support the preferential use of septal pacing to minimize pacing-induced ventricular dysfunction

and underscore the importance of advanced imaging techniques in the evaluation of paced patients.

### Conclusion

This study demonstrates that right ventricular septal pacing is associated with more favorable left ventricular systolic performance compared with apical pacing when assessed using both conventional and three-dimensional echocardiography. Preservation of global ejection fraction in the septal pacing group indicates a more physiological pattern of ventricular activation, while the observed differences in longitudinal strain highlight the ability of deformation imaging to detect subtle mechanical alterations not evident with ejection fraction alone. The significant impairment of septal strain in apical pacing suggests greater electrical and mechanical dyssynchrony, which may predispose patients to pacing-induced ventricular dysfunction over time. These findings support septal pacing as a preferable alternative to apical lead placement for maintaining ventricular mechanics and underscore the clinical value of advanced echocardiographic techniques in the functional evaluation and follow-up of paced patients.

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### Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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