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Single- and dual-site ventricular pacing entirely through the coronary sinus for patients with prior tricuspid valve surgery

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Abstract

Purpose Transvenous right ventricular pacing has traditionally been avoided after surgical tricuspid valve repair or replacement because of possible valvular dysfunction. Epicardial pacing has been used but it requires surgical thoracotomy and has higher lead failure rates when compared to transvenous pacing. We evaluated the lead stability and clinical outcomes in patients with isolated coronary sinus (CS) lead due to relative contraindication to transvenous pacing from prior tricuspid valve (TV) surgery.

Methods We retrospectively examined a single-center cohort of 34 patients with TV disease and/or surgery who underwent permanent pacemaker implantation with a left ventricular CS lead as the only ventricular pacing lead (to avoid crossing the TV). The clinical outcome, echocardiographic data, and pacing thresholds were evaluated at follow-up.

Results We implanted 19 patients with a single-CS lead and 15 patients with dual-CS leads. The average left ventricular ejection fraction was 56 ± 13% prior to lead implantation and remained stable at 2-year follow-up. The tricuspid regurgitation remained mild at follow-up. The average lead pacing threshold was 1.2 ± 0.6 V × ms at implant and 1.1 ± 0.4 V × ms at 2-year follow-up ($P = 0.39$). For patients with dual-CS leads, the pacing threshold was 1.2 ± 0.7 V × ms at implant and 1.1 ± 0.5 V × ms at 2-year follow-up ($P = 0.52$).

Conclusions The use of ventricular pacing entirely through the CS is an effective and minimally invasive method that provides stable pacing for patients with prior TV surgery in whom transvenous lead placement either is not possible or is relatively contraindicated.

Keywords Cardiac resynchronization therapy · Tricuspid valve surgery · Tricuspid valve replacement · Tricuspid valve repair · Left ventricular venous lead

1 Introduction

Transvenous right ventricular (RV) pacing is routinely performed during pacemaker implant because of its ease of access and long-term lead stability. In patients with a native tricuspid valve (TV), significant tricuspid regurgitation (TR) has been reported in up to 16% of transvenous RV pacemakers [1]. The most common causes of lead-associated TV dysfunction are lead impingement of the TV leaflets (39% of patients), lead adhesion (34%), leaflet perforation (17%), and lead entanglement in the TV (10%) [2]. Despite these risks, small, prospective studies do not show a significant development of new TR with RV pacing in the short term [3, 4]. In patients with prior surgical TV repair, these risks may be greater. Retrospective data show a 5-year incidence of severe TR in 42% of patients after valve repair in those with a transvenous RV lead, which is almost twice as high as those who had TV repair without a transvenous lead [5]. In another analysis by Mazine et al., the presence of transvenous RV lead after TV repair causing moderate-severe TR is estimated to be 2.45 times higher than patients without transvenous lead [6]. Therefore, transvenous RV pacing has traditionally been avoided after TV surgery whenever possible because it may cause valvular dysfunction. Mechanical TV prosthesis is considered a contraindication of transvenous RV lead implantation.

Cardiac surgeries, and especially valve replacement, are frequently associated with the need for permanent pacemaker implantation with an overall incidence of up to 2.4% [7]. For TV surgery, the incidence of permanent pacemaker implantation is reported to be 21%, mainly due to post-operative advanced heart block and sick-sinus syndrome [8]. Commonly

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Table 1 Baseline demographics

Patient demographic ($n = 34$)	Number (%)
Age (years)	59 ± 14
Females	20 (59%)
Atrial fibrillation	21 (62%)
Hypertension	17 (50%)
Congestive heart failure	17 (50%)
Coronary artery disease	11 (32%)
Diabetes	13 (38%)
Cerebrovascular accident	4 (12%)
Tricuspid valve procedures	
Bioprosthetic TV replacement	16 (47%)
TV repair	17 (50%)
No TV procedure, baseline with moderate, or worse TV regurgitation	1 (3%)

TV tricuspid valve

associated risk factors for pacemaker implantation after TV operation include preoperative left bundle branch block, annuloplasty ring use, and need for temporary pacing post-op [8].

When RV endocardial pacing is not possible or desirable, epicardial pacing has been used, but it requires a thoracotomy and has higher chronic pacing thresholds and lead failure rates when compared to endocardial pacing [9, 10]. Primary ventricular pacing entirely through the coronary sinus (CS) is a viable alternative because it avoids both invasive surgical intervention and potential TV disruption. However, this has only been evaluated in small, retrospective studies involving single-site CS pacing in patients with normal left ventricular (LV) function [11, 12]. In this retrospective study, we reviewed our experience with implanting both single- and dual-CS leads in patients with prior TV surgery.

Table 2 Indications for coronary sinus pacing and lead position

	Number (%)
Indication for pacemaker ($n = 34$)	
High-grade heart block	21 (62%)
Sick-sinus syndrome	11 (32%)
LV systolic dysfunction	7 (21%)
Indication for single-CS lead ($n = 19$)	
High-grade heart block	11 (58%)
Sick-sinus syndrome	8 (42%)
LV systolic dysfunction	1 (5%)
Indication for dual-CS leads ($n = 15$)	
High-grade heart block	10 (67%)
Sick-sinus syndrome	3 (20%)
LV systolic dysfunction	6 (40%)
Position of CS leads	
Anterior interventricular vein	27 (79%)
Lateral vein	17 (50%)
Middle cardiac vein	4 (12%)
Posterior vein	1 (3%)

CS coronary sinus, *LV* left ventricular

2 Methods

2.1 Study patients

From 2015 to 2018, we retrospectively reviewed 34 consecutive patients at our institutions (Los Angeles County Medical Center and Keck Hospital of University of Southern California, Los Angeles, CA, USA) who underwent permanent pacemaker implantation with an LV CS lead as the only ventricular pacing lead and prior TV repair or replacement, to avoid crossing the TV. We excluded patients with super vena cava and/or subclavian vein obstruction that would impede the advancement and manipulation of transvenous leads. The study was approved by our local Institutional Review Board at the Keck University of Southern California School of Medicine. The study protocol adheres to the ethical guidelines of the 2008 Declaration of Helsinki.

2.2 Study outcomes

We collected patients' baseline demographics, indications for pacing, and echocardiographic data prior to pacemaker implantation. The pacing thresholds were evaluated based on our institution's standard follow-up times. The echocardiographic data and pacing threshold data were collected at 1 month, 3 months, 12 months, and 24 months. Procedural complications, pacemaker or lead related problems, and death of patients were recorded.

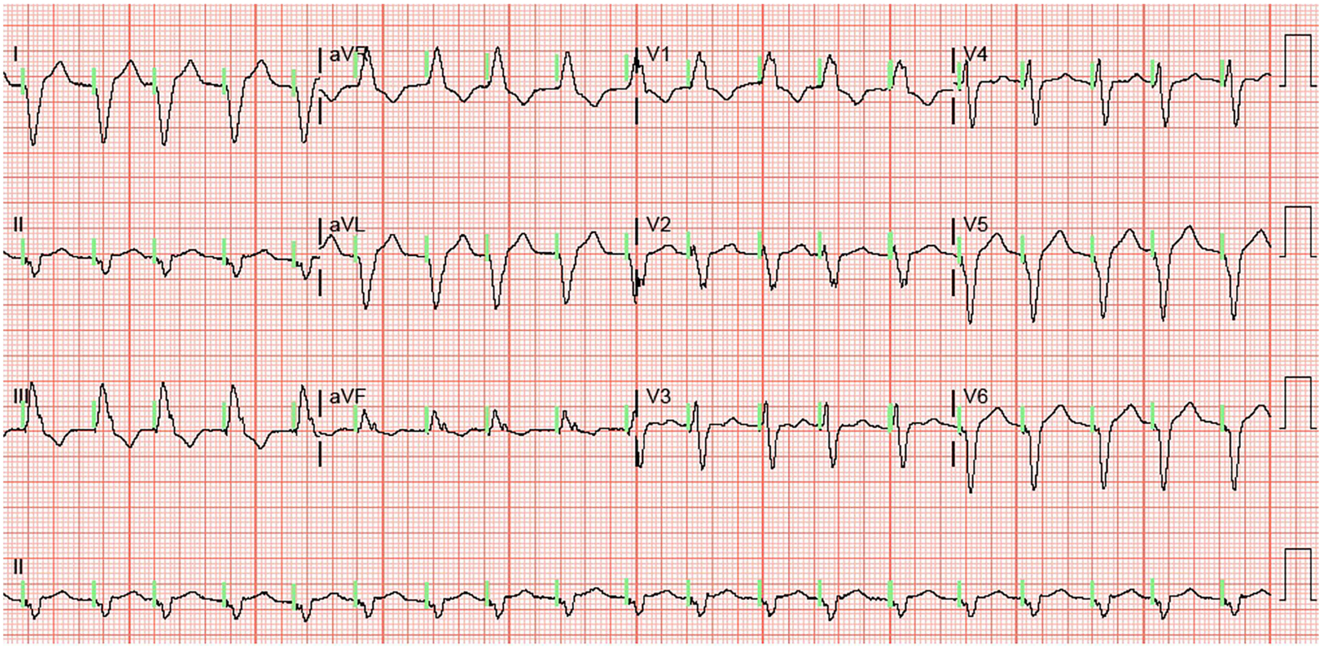

Fig. 1 Electrocardiogram after dual-coronary sinus lead implantation in the anterior interventricular vein and lateral vein. Note the right bundle branch block pattern and extreme axis deviation commonly seen in cardiac resynchronization therapy

2.3 Statistical analysis

Categorical variables are reported as absolute and relative frequencies (percentages) and continuous variables are reported as mean ± standard deviation. Two-tailed, paired *T* test was performed using GraphPad Prism version 8 (GraphPad Software Inc., La Jolla, CA, USA) to compare the baseline and follow-up data for echocardiographic LV and TV function and lead threshold. A two-tailed P value ≤ 0.05 was considered to indicate statistical significance.

3 Results

3.1 Study population

We evaluated 19 patients with a single-CS lead and 15 patients with dual-CS leads. Patient demographics are shown in Table 1. Thirty-three patients had a previous TV surgery (16 patients with bioprosthetic TV replacement and 17 patients with TV repair) and one patient had native TV with baseline moderate TR. Of the 33 patients with TV surgery, 10 patients had concomitant mitral and aortic valve surgery, and 10 patients had concomitant mitral valve surgery. Thirty patients in sinus rhythm had a right atrial lead implanted and four patients in persistent atrial fibrillation did not. All of the implanted CS leads were standard bipolar or multipolar CS leads. Dual chamber pacemakers were used for cases with a single-CS lead, and cardiac resynchronization therapy (CRT) pacemakers were used for cases with dual-CS leads.

The indication for pacing is shown in Table 2. The most common indications for pacemaker implantation were high-grade AV block followed by sick-sinus syndrome and LV dysfunction. The anterior interventricular vein (AIV) was preferentially selected for ventricular pacing to minimize the risk of lead migration and achieve early septal activation for single-site pacing. In patients with baseline LV systolic dysfunction, we preferentially implanted dual-CS leads in the AIV and lateral vein in an attempt to achieve CRT pacing (Fig. 1). We also preferentially implanted dual-CS leads for redundancy in patients who were pacemaker dependent due to risk of LV lead dislodgement. The procedural time for single CS lead was 90–120 min and dual CS lead 120 to 150 min. The positions of the CS leads are presented in Table 2. An example of both single-site and dual-site pacing are shown in Fig. 2.

3.2 Clinical follow-up at 1- and 2 years

Table 3 shows the echocardiographic and lead interrogation data for both single- and dual-CS lead patients at implant and during follow-up. The average left ventricular ejection fraction (LVEF) was 56 ± 13% prior to lead implantation and remained stable at 1- and 2-year follow-up (Fig. 3). Similarly, the TR grade remained stable at 2-year follow-up. The average implantation R-wave sensed was 8.3 ± 4.5 mV, lead pacing threshold was 1.3 ± 0.9 V × ms, and lead impedance was 930 ± 226 Ω. At 1-year follow-up, the R-wave amplitude increased to 11.1 ± 5.9 mV ($P = 0.03$), but the lead pacing threshold and impedance remained stable at 1- and 2-year follow-up. Table 4 shows the echocardiographic and lead

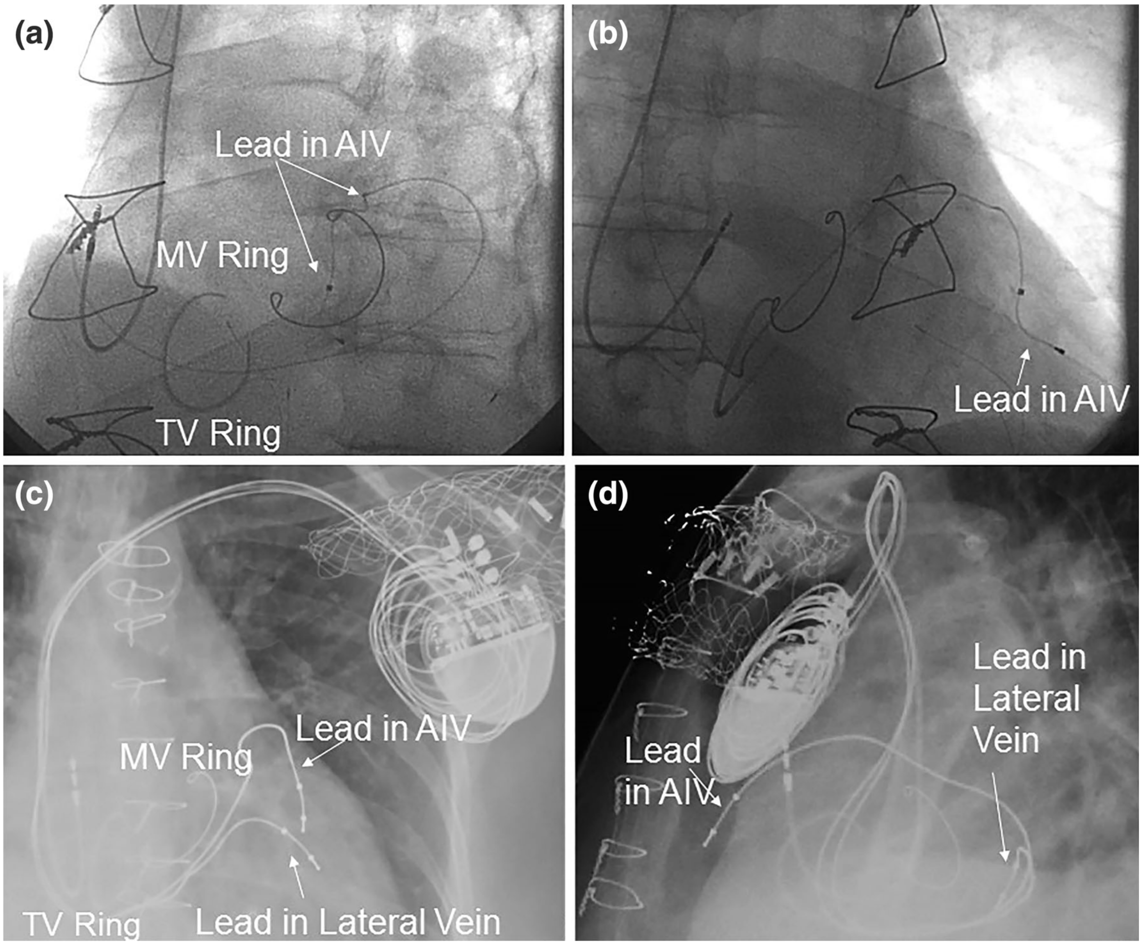

Fig. 2 Chest radiographs of two patients who underwent ventricular pacing lead implantation though the coronary sinus (CS) to avoid crossing the tricuspid valve. Single-CS lead implanted in the anterior interventricular vein (AIV) in anterior-posterior view (**a**) and lateral view (**b**). Dual-CS lead implantation in AIV and lateral vein in anterior-posterior view (**c**) and lateral view (**d**). AIV anterior interventricular vein, MV mitral valve, TV tricuspid valve

Table 3 Echocardiogram and lead interrogation at implantation and follow-up for all patients

All patients—echo 1 year ($n = 18/34$)	**Pre-pacemaker implant**	**1-Year follow-up**	***p* value**
Left ventricular ejection fraction (%)	56 ± 13	58 ± 9	0.41
Left ventricular end-diastolic diameter (cm)	4.7 ± 0.7	4.6 ± 0.9	0.52
Tricuspid regurgitation (0 = none, 1 = mild, 2 = moderate, 3 = mod-severe, 4 = severe)	0.9 ± 1.0	0.5 ± 0.7	0.09
All patients—echo 2 years ($n = 11/34$)	**Pre-pacemaker implant**	**2-Year follow-up**	***p* value**
Left ventricular ejection fraction (%)	56 ± 14	59 ± 7.2	0.29
Left ventricular end-diastolic diameter (cm)	4.8 ± 5	4.7 ± 0.4	0.51
Tricuspid regurgitation (0 = none, 1 = mild, 2 = moderate, 3 = mod-severe, 4 = severe)	0.9 ± 1.4	0.8 ± 0.9	0.75
All patients—pacing threshold 1 year ($n = 15/34$)	**Implant**	**1-Year follow-up**	***p* value**
R wave amplitude (mV)	8.3 ± 4.5	11.1 ± 5.9	0.03
Pacing threshold × pulse width (V × ms)	1.3 ± 0.9	1.3 ± 1.1	0.92
Impedance (ohms)	930 ± 226	981 ± 276	0.30
All patients—pacing threshold 2 years ($n = 11/34$)	**Implant**	**2-Year follow-up**	***p* value**
R wave amplitude (mV)	8.2 ± 4.3	11.1 ± 5.7	0.01
Pacing threshold × pulse width (V × ms)	1.2 ± 0.6	1.1 ± 0.4	0.39
Impedance (ohms)	998 ± 236	1083 ± 201	0.23

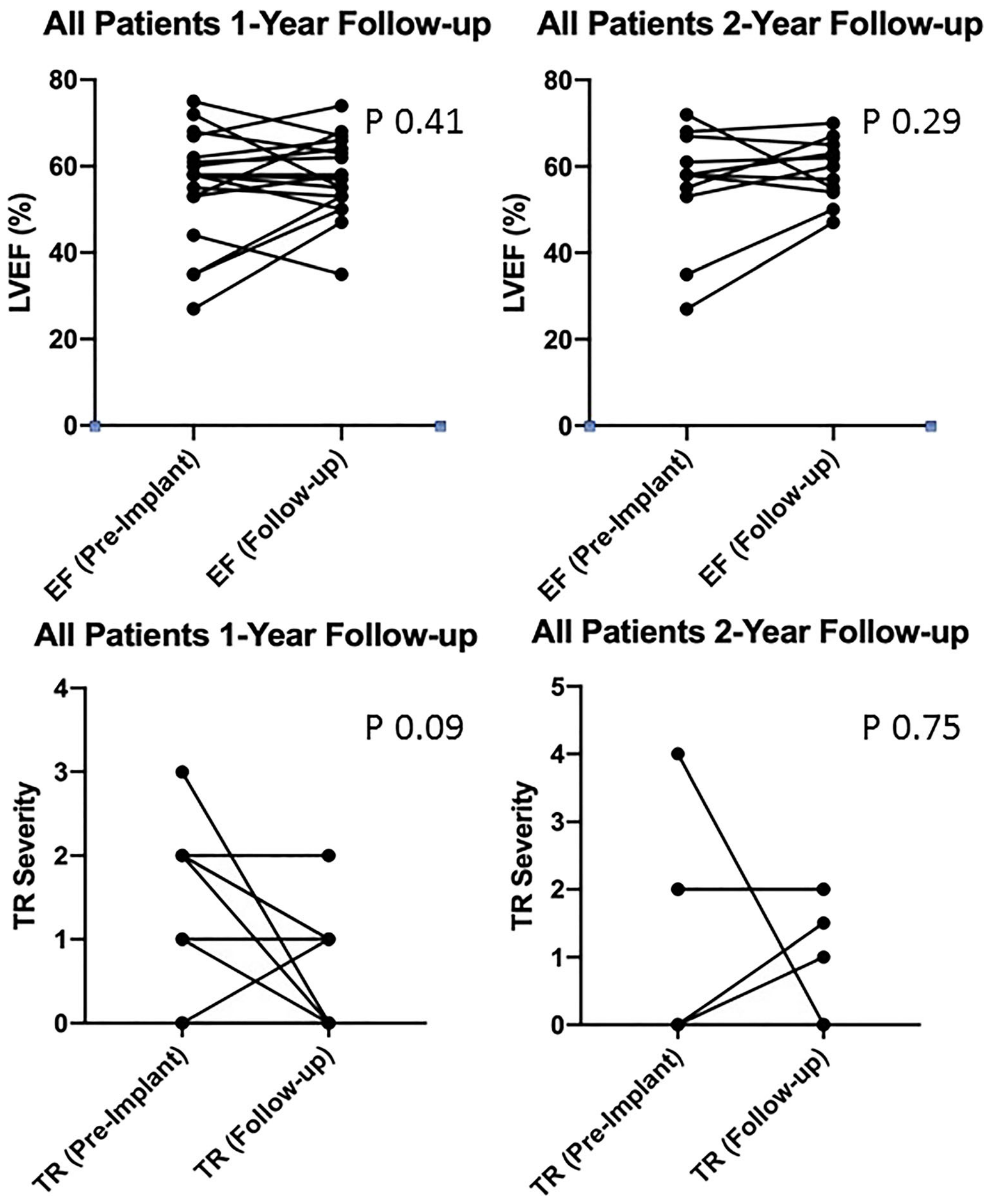

Fig. 3 Echocardiographic outcomes for all patients at 1- and 2-year follow-ups. The LVEF and TR grade remained stable at 2-year follow-up. LVEF left ventricular ejection fraction, TR tricuspid regurgitation

interrogation data for single-CS lead patients at implant and during follow-up. For patients with a single-CS lead, the LVEF was preserved at pacemaker implant and remained unchanged at 1- and 2-year follow-ups (Fig. 4). The TR grade remained stable at follow-up. The average implantation R-wave sensed was 7.8 ± 4.4 mV, lead pacing threshold was 1.3 ± 1.1 V × ms, and lead impedance was 955 ± 273 Ω. The R-wave sensing amplitude mildly increased while the lead pacing threshold and impedance remained stable at 1- and 2-year follow-up. Table 5 shows the echocardiographic and lead interrogation data for dual-CS lead patients. For patients with dual-CS leads, the average pre-pacemaker implant LVEF was 47 ± 17%. Although not reaching statistical significance, patients with baseline reduced LVEF show an improved LVEF at follow-up; those with normal LVEF showed preserved function at follow-up (Fig. 5). The TR grade remained stable at follow-up. The average implantation R-wave sensed was 8.8 ± 4.9 mV, lead pacing threshold was 1.3 ± 0.7 V × ms, and lead impedance was 912 ± 194 Ω. Like single-CS lead patients, the R-wave sensing amplitude mildly increased while the lead pacing threshold and impedance remained stable at 1- and 2-year follow-ups.

3.3 Complications—lead migration

Although there were no cases of diaphragmatic stimulation or intraoperative nonstable lead position, two patients eventually had lead migration that resulted in an increased pacing threshold requiring reimplantation. Both patients received a single-CS lead (EASYTRAK® 2 bipolar lead, Boston Scientific,

Table 4 Echocardiogram and lead interrogation at implantation and follow-up for single-CS lead

Single-CS lead—echo 1 year (n = 12/34)	**Pre-pacemaker implant**	**1-Year follow-up**	***p* value**
Left ventricular ejection fraction (%)	60 ± 9	59 ± 10	0.75
Left ventricular end-diastolic diameter (cm)	4.6 ± 0.7	4.7 ± 1.0	0.74
Tricuspid regurgitation (0 = none, 1 = mild, 2 = moderate, 3 = mod-severe, 4 = severe)	0.6 ± 1.0	0.3 ± 0.5	0.30
Single-CS lead—echo 2 years (n = 7/34)	**Pre-pacemaker implant**	**2-Year follow-up**	***p* value**
Left ventricular ejection fraction (%)	62 ± 7.3	61 ± 6.3	0.91
Left ventricular end-diastolic diameter (cm)	4.7 ± 0.4	4.6 ± 0.4	0.54
Tricuspid regurgitation (0 = none, 1 = mild, 2 = moderate, 3 = mod-severe, 4 = severe)	0.6 ± 1.5	0.4 ± 0.6	0.76
Single-CS lead—pacing threshold 1 year (n = 9/34)	**Implant**	**1-Year follow-up**	***p* value**
R wave amplitude (mV)	7.8 ± 4.4	11.3 ± 6.1	0.08
Pacing threshold × pulse width (V × ms)	1.3 ± 1.1	1.2 ± 0.6	0.72
Impedance (ohms)	955 ± 273	910 ± 214	0.58
Single-CS lead—pacing threshold 2 years (n = 8/34)	**Implant**	**2-Year follow-up**	***p* value**
R wave amplitude (mV)	7.2 ± 3.2	11.9 ± 5.3	0.01
Pacing threshold × pulse width (V × ms)	1.1 ± 0.6	1.0 ± 0.4	0.61
Impedance (ohms)	968 ± 275	1003 ± 178	0.75

Natick, MA, USA) and had intermittent failure to capture with resultant syncope. One case occurred 6 days' post-initial CS lead implant in the lateral vein for complete heart block after post-myocardial infarction repair of ventricular septal defect and TV. An RV lead (INGEVITY™ MRI, Boston Scientific) was added to convert to a CRT system. The patient eventually died during the same hospitalization due to worsening cardiogenic shock.

The other case occurred 29 months from the initial CS lead implanted in AIV. An RV lead (ENDOTAK RELIANCE®, Boston Scientific) was added to convert to a CRT system. In both cases, given the syncope from lead migration, they were converted to a CRT system. The LV lead output was increased to maintain CRT. We did not disable the LV lead pacing given patient's estimated high pacing burden requirement so attempt to maintain CRT pacing. One of the patients developed moderate TR after the implant of the RV lead over his bioprosthetic TV. Both cases were included in the follow-up echo evaluation prior to the addition of the RV lead. No other patient developed CS lead malfunction or pacing abnormalities. No patients with a single AIV lead placement suffered lead dislodgment or migration.

4 Discussion

Transvenous RV pacemaker and implantable cardioverter defibrillator (ICD) leads are associated with significant increases in TR grade [4, 13–15]. RV septal and apical pacing has been compared to and has shown no significant difference in the incidence of TR [4, 15]. More importantly, transvenous RV pacemaker is an independent risk factor for TR recurrence and increased mortality after TV repair [6]. These findings have led to development of alternative pacing approaches such as isolated CS pacing to avoid crossing the surgically repaired or replaced TV.

In this study, we evaluated the echocardiographic and pacemaker lead outcomes of consecutive patients with TV disease who had ventricular pacing (single- or dual-CS leads) entirely through the CS to avoid crossing the TV. At 2-year follow-up, isolated CS lead pacing was not associated with an increase in TR grade and coincides with a prior report [11]. A recent prospective study on "native" TV showed that isolated CS pacing does not prevent TR when compared with transvenous RV pacing [4]. However, this may be due in part to transvenous RV pacing having less TR risk in native TV when compared to patients requiring surgical repair or replacement. In patients with a high TR recurrence risk, such as our patients with prior surgical TV requiring pacemaker, isolated CS pacing may still be beneficial when compared to traditional transvenous RV pacing.

At 2-year follow-up, there were two cases of lead migration for patients with a single-CS lead. Despite the complication, the overall pacing threshold for our patients remained stable and replicate prior reported findings by Sideris et al. [12] and Noheria et al. [11]. Both of these patients received a CS lead implanted in a lateral branch vein. The majority of our patients with a single lead employed an AIV location. Retrospective analysis of the COMPANION trial showed similar 2-year lead stability comparing anterior vs lateral and posterior LV lead position without significant differences in lead-related adverse events [16]. In our cohort, we have not experienced diaphragmatic stimulation and this is likely due to the majority of our patients having anterior LV leads. Anteriorly positioned LV leads have a low reported incidence of diaphragmatic stimulation (0.3%) vs. lateral (8.4%) and posterior (2%) leads [17].

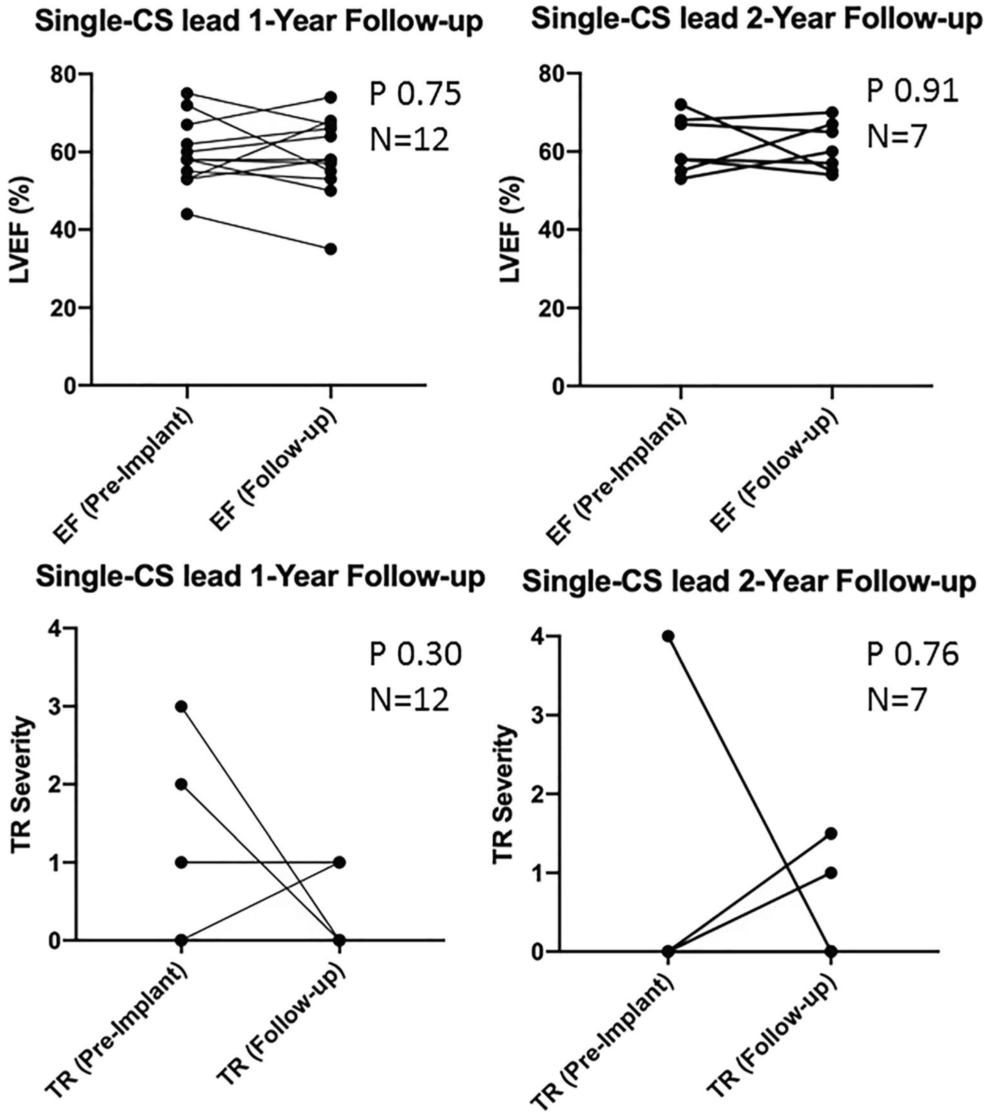

Fig. 4 Echocardiographic outcomes for patients with single-CS leads at 1- and 2-year follow-ups. The LVEF and TR grade remained stable at 2-year follow-up. LVEF left ventricular ejection fraction, TR tricuspid regurgitation.

In the case of increasing pacing threshold over time, the AIV position provides room for high-output pacing with low-risk for diaphragmatic stimulation. Salcedo and colleagues have previously demonstrated the feasibility of achieving CRT in a patient with a mechanical TV prosthesis in a CRT defibrillator system [18]. To our knowledge, this is the first study to assess the long-term feasibility of implanting a dual-CS leads pacing system entirely through the CS. Similar stable thresholds were achieved with the dual-CS lead group at follow-up. There were no cases of lead dislodgement in the dual-CS lead group.

RV pacing is associated with pacemaker-induced cardiomyopathy. In recent cohort, the incidence has been reported as high as 12.3% in those with high RV pacing burden (> 20%) [19]. In our study, we did not observe LV systolic dysfunction with high LV pacing burden. The LVEF and LV end-diastolic diameter remained stable at 2-year follow-up despite high ventricular pacing burden of 74 ± 40%, which replicate prior series of isolated CS pacing [4, 11]. In the dual-CS lead group, there was a general trend towards improvement in LVEF, which is similar to prior reported LVEF improvement seen with traditional CRT systems [20]. Multiple studies have shown that isolated LV pacing (without synchronized LV fusion pacing) can be as effective as biventricular pacing in treating cardiomyopathy [21–23]**.** This "protective effect" of epicardial LV pacing may be why we did not observe LV dysfunction in our study population despite a high ventricular pacing burden in our single- and dual-CS lead patients (Tables 4 and 5). However, these studies employed lateral vein placement in patients with underlying left bundle branch block and significant LV dysfunction. Whether or not long-term pacing from the AIV results in LV dysfunction in our study population has yet to

Table 5 Echocardiogram and lead parameters at implant and follow-up for dual-coronary sinus lead patients

Dual-CS lead—echo 1 year ($n = 6/15$)	**Pre-pacemaker implant**	**1-Year follow-up**	***p* value**
Left ventricular ejection fraction (%)	47 ± 17	55 ± 6.4	0.16
Left ventricular end-diastolic diameter (cm)	4.9 ± 0.5	4.5 ± 0.8	0.32
Tricuspid regurgitation (0 = none, 1 = mild, 2 = moderate, 3 = mod-severe, 4 = severe)	1.5 ± 0.8	1 ± 0.9	0.08
Dual-CS lead—echo 2 years ($n = 4/15$)	**Pre-pacemaker implant**	**2-Year follow-up**	***p* value**
Left ventricular ejection fraction (%)	56 ± 14	59 ± 7.2	0.80
Left ventricular end-diastolic diameter (cm)	4.8 ± 5	4.7 ± 0.4	0.33
Tricuspid regurgitation (0 = none, 1 = mild, 2 = moderate, 3 = mod-severe, 4 = severe)	0.9 ± 1.4	0.8 ± 0.9	0.28
Dual-CS lead—pacing threshold 1 year ($n = 6/15$)	**Implant**	**1-Year follow-up**	***p* value**
R wave amplitude (mV)	8.8 ± 4.9	10.8 ± 6.3	0.25
Pacing threshold × pulse width (V × ms)	1.3 ± 0.7	1.4 ± 1.3	0.74
Impedance (ohms)	912 ± 194	1034 ± 313	0.04
Dual-CS lead—pacing threshold 2 years ($n = 3/15$)	**Implant**	**2-Year follow-up**	***p* value**
R wave amplitude (mV)	9.5 ± 5.6	9.6 ± 6.7	0.58
Pacing threshold × pulse width (V × ms)	1.2 ± 0.7	1.1 ± 0.5	0.52
Impedance (ohms)	1038 ± 190	1189 ± 192	0.09

CS coronary sinus

be demonstrated. One could postulate that pacing in this location alone would be similar to RV apical pacing.

Roughly half of the dual-CS lead patients had normal LVEF at baseline (Fig. 5). The high prevalence of implanting dual-CS leads in normal LVEF patients in the latter half of our study occurred because of the lead migration cases we experienced with single-CS lead implants in patients who were pacemaker dependent. This practice provides increased redundancy in the event of loss of capture and is especially important in patients who are pacemaker dependent. Both of our lead displacement cases occurred with a single experienced CRT operator, involved the use of bipolar lead. The lead dislodgement rate was recently reported to be 2.1% for quadripolar and 5% for bipolar LV lead [24]. Implanting dual-CS leads requires slightly more time, effort, and resources, but we believe this strategy provides more redundancy than using a single lead in pacemaker dependent patients. Thus far, we have not experienced any evidence of loss of capture or syncopal events in the dual-CS lead group.

Our study demonstrated relative procedural safety when implanting two CS leads. This is in contrast to the recently reported V3 trial, in which a second LV lead was implanted in non-responders and negative responders to standard CRT. This resulted in a high perioperative complication rate (20%; 9 of 44 patients), including five infections that led to three system explants and one patient death due to septic shocks from endocarditis, two pneumothoraces, and two large hematomas [25]. Our study had a very different patient population from the V3 trial given that our patients had valvular heart disease status post-repair requiring pacing, rather than being non-responders to standard CRT. Negative and non-responders are associated with an elevated 2-year mortality of up to 29% and 17%, respectively [26]. In addition, unlike the V3 trial in which a current CRT system was revised to add a second LV lead, our patients had a new device implanted (either new device requirement post-surgery or had a prior device explanted during the cardiac surgery). Device revision is associated with 5-fold increased risk of infection [27]. In another study evaluating ICD revisions, one-third of ICD patients without signs of sepsis had asymptomatic bacterial colonization of the generator pockets or leads, and device revisions led to 7.5% device infection rate in those with positive culture swab compared to 2.4% of patients with negative culture [28]. *De novo* implants in our population likely led to a decreased risk of infection in observed in our study.

4.1 Alternative pacing approaches

In addition to isolated CS pacing, epicardial pacing, and RV transvenous pacing, several alternative methods such as His bundle pacing (HBP) [29] and leadless pacemaker [30–32] have been reported in patients with prior TV surgery.

HBP provides a more physiologic native conduction to prevent ventricular dyssynchrony than does CS or RV pacing. A recent case series reported by Sharma et al. [29] demonstrated 93% feasibility when performing HBP in patients with bioprosthetic cardiac valves. Unsuccessful cases were all in patients with prior transcatheter aortic valve replacement likely from increased infranodal conduction defect in preventing effective HBP. However, only 10 patients in this series had a TV ring and none had TV replacement. Further study is needed to assess the long-term HBP lead stability and safety in patients with surgical TV if even feasible.

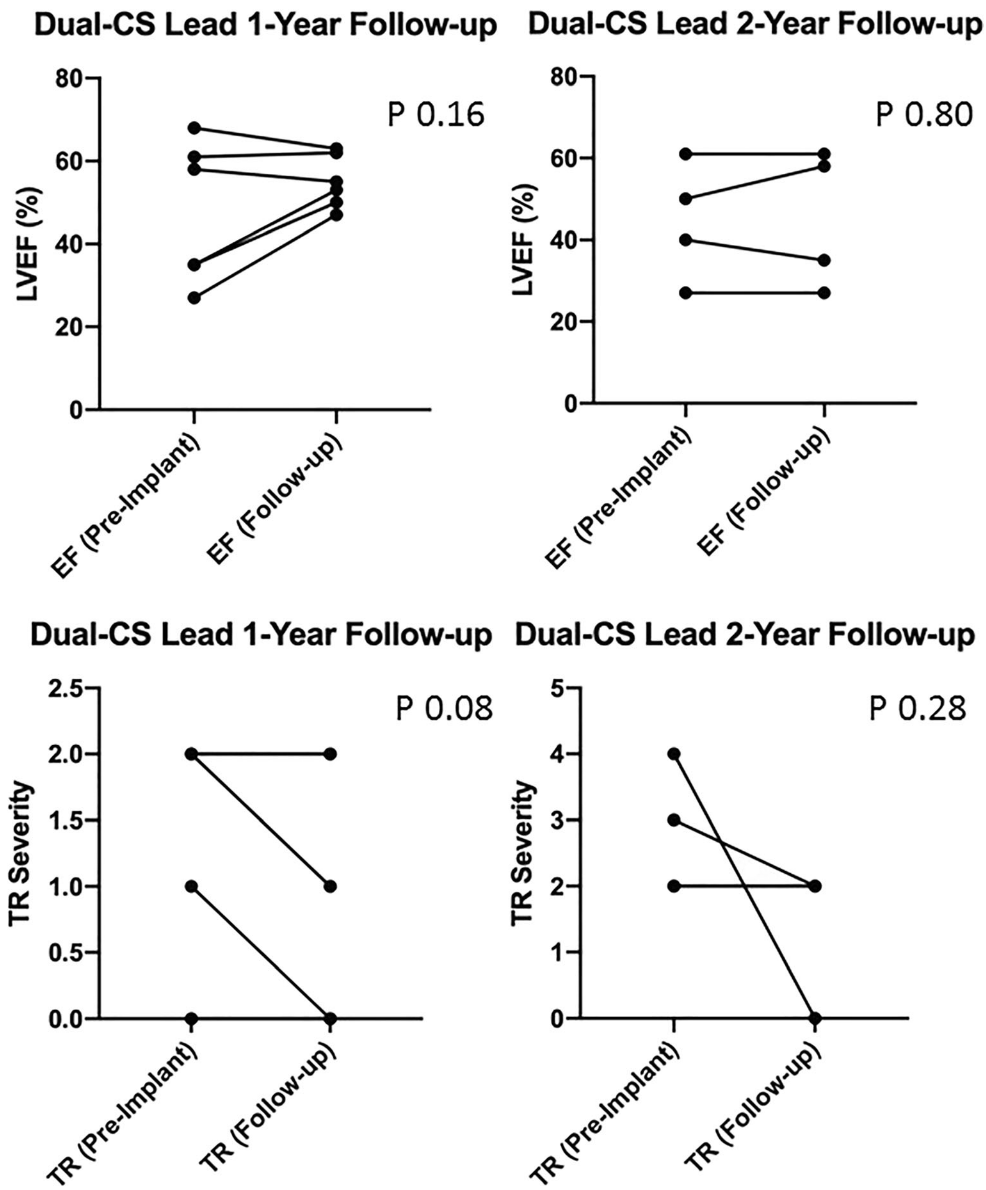

Fig. 5 Echocardiographic outcomes for patients with dual-CS leads at 1- and 2-year follow-ups. The LVEF and TR grade remained stable at 2-year follow-up. LVEF left ventricular ejection fraction, TR tricuspid regurgitation

Similar to HBP, leadless pacemaker had also been reported in TV surgery patients but there is no large, long-term study. Currently, this only allows for ventricular-only pacing and does not maintain AV synchrony or enable for potential CRT therapy. Most data were from isolated case reports [30, 32] and the Nanostim registry [31], which included a small number of patients with TV surgery. In a short, 2-month follow-up, leadless pacing was not associated with worsening RV and TV function [33].

4.2 Limitations

The conclusions drawn from this study are limited given the small sample size and retrospective nature. Moreover, we do not have a matched comparison group of patients who underwent traditional RV endocardial pacing. Our retrospective study precludes the ability to identify if there were any patients that were not considered for this approach or who might have had CS leads attempted but that were not successful and converted to a traditional RV lead system. Our report only allows for a conclusion that the approach is feasible and that further study is necessary to demonstrate whether this approach is superior to traditional pacing. In addition, not all of the patients had long-term follow-up of pacing parameters or echocardiographic data, which may alter the observations.

In our dual-CS lead group, the post-implant electrocardiogram (Fig. 1) supports the feasibility of CRT pacing. However, we lack hemodynamic data or echocardiographic characterization of dyssynchrony to support any improvement with dual-CS lead pacing. Further study is necessary to demonstrate successful resynchronization therapy.

5 Conclusion

The use of ventricular pacing entirely through the CS is an effective and less invasive method in providing stable pacing for patients with prior TV surgery compared to epicardial lead placement. In addition to a single-CS lead, it is possible (for redundancy) to implant dual-CS leads in patients with underlying cardiomyopathy or who are pacemaker dependent. It should be considered that the practice of dual-CS leads implantation may be associated with increase periprocedural complications [25], even though it is not observed in our study. Until further long-term study is available that includes alternative methods (e.g. HBP, leadless pacemaker) in this population, isolated CS pacing is a reasonable alternative to epicardial and transvenous RV pacing.

Compliance with ethical standards

The study was approved by our local Institutional Review Board at the Keck University of Southern California School of Medicine. The study protocol adheres to the ethical guidelines of the 2008 Declaration of Helsinki.

Conflict of interest R. Doshi is a consultant and received fellowship support from Abbott Medical and Boston Scientific.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was provided according to institutional protocols.

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