Safety and feasibility of conduction system pacing in patients with congenital heart disease

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Abstract

Introduction: Conduction system pacing (CSP) has emerged as an ideal physiologic pacing strategy for patients with permanent pacing indications. We sought to evaluate the safety and feasibility of CSP in a consecutive series of unselected patients with congenital heart disease (CHD). Methods: Consecutive patients with CHD in which CSP was attempted were included. Safety and feasibility, implant tools and electrical parameters at implant and at follow-up were evaluated. Results: A total of 20 patients were included (10 with a previous device). Ten patients had complex forms of CHD, 9 moderate defects and 1 a simple defect. His bundle pacing (HBP) or left bundle branch area pacing (LBBAP) were achieved in all patients (10 HBP, 5 LBBP and 5 left ventricular septal pacing). Procedure times and fluoroscopy times were prolongued (126±82 min and 27±30 min, respectively). CSP lead implant times widely varied ranging from 4 to 115 minutes, (mean 31±28 min) and the use of multiple delivery sheaths was frequent (50%). The QRS width was reduced from 144±32 ms at baseline to 116±16 ms with CSP. Implant electrical parameters included: CSP pacing threshold 0.85±0.61V; R wave amplitude 9.8±9.2mV and pacing impedance 735±253 Ohms, and remained stable at a median follow-up of 478 days (IQR 225-567). Systemic ventricle systolic function and NYHA class (1.50±0.51 vs 1.10±0.31; p=0.008) significantly improved at follow-up. Lead revision was required in one patient at day-4. Conclusions: Permanent CSP is safe and feasible in patients with CHD although implant technique is complex.

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Conduction system pacing in congenital heart disease

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Abstract

Introduction : Conduction system pacing (CSP) has emerged as an ideal physiologic pacing strategy for patients with permanent pacing indications. We sought to evaluate the safety and feasibility of CSP in a consecutive series of unselected patients with congenital heart disease (CHD).

Methods : Consecutive patients with CHD in which CSP was attempted were included. Safety and feasibility, implant tools and electrical parameters at implant and at follow-up were evaluated.

Results : A total of 20 patients were included (10 with a previous device). Ten patients had complex forms of CHD, 9 moderate defects and 1 a simple defect. His bundle pacing (HBP) or left bundle branch area pacing (LBBAP) were achieved in all patients (10 HBP, 5 LBBP and 5 left ventricular septal pacing). Procedure times and fluoroscopy times were prolongued (126±82 min and 27±30 min, respectively). CSP lead implant times widely varied ranging from 4 to 115 minutes, (mean 31±28 min) and the use of multiple delivery sheaths was frequent (50%). The QRS width was reduced from 144±32 ms at baseline to 116±16 ms with CSP. Implant electrical parameters included: CSP pacing threshold 0.85±0.61V; R wave amplitude 9.8±9.2mV and pacing impedance 735±253 Ohms, and remained stable at a median follow-up of 478 days

(IQR 225-567). Systemic ventricle systolic function and NYHA class (1.50±0.51 vs 1.10±0.31; p=0.008) significantly improved at follow-up. Lead revision was required in one patient at day-4.

Conclusions : Permanent CSP is safe and feasible in patients with CHD although implant technique is complex.

Keywords : conduction system pacing; His bundle pacing; Left bundle branch area pacing; congenital heart disease.

Introduction

Conduction system pacing (CSP) including His bundle pacing (HBP) and left bundle branch area pacing (LBBAP) has been demonstrated to be safe and feasible in a wide range of patients with bradycardia pacing indications such as AV nodal or infrahisian AV block[1-2]. Recently, CSP has also been shown to be effective in other more challenging scenarios including pacemaker induced cardiomyopathy and patients with indications for cardiac resynchronization therapy[3-5]. Patients with congenital heart disease (CHD) are known to be at higher risk of developing conduction disturbances, especially in some specific anatomic variants[6]. Anatomic challenges are common, particularly if the patient has undergone surgical correction/palliation of the primary defect or if prosthetic valves, surgical patches or conduits are present[7-11]. On the other hand, CHD patients may derive the most benefit with physiological pacing considering young age at the time of implant as well as presence of structural heart disease, which have been associated with the developement of pacemaker induced cardiomyopathy. However, data on safety and feasibility of CSP in CHD is scarce and currently limited to case reports and small series of adult patients with congenitally corrected transposition of the great arteries (cc-TGA) and congenital complete heart block[12-13].

The aim of this study was to evaluate the safety and feasibility of CSP in a consecutive series of unselected patients with a wide range of CHD subtypes, including complex anatomies and post-surgical correction status.

Methods

This is a retrospective, multicenter series of consecutive patients with CHD and a permanent pacing indication according to current guidelines[6,14]. Patients with a previous device and an indication for new ventricular pacing lead implant or upgrade to a CRT device were also included. The study was approved by the Institutional Committee on Human Research of the participating hospitals, and all patients gave written informed consent before the procedure.

Implant Procedure Description

All implants were performed under general anesthesia or conscious sedation. Antibiotic prophylaxis with 2g cefazolin or 1g vancomycin was used. Vascular access was obtained by fluoroscopic or ultrasound-guided direct puncture of the subclavian or axillary veins or via cephalic vein cutdown. A subcutaneous pocket was created in those patients without previous device.

Special attention was given to pre-implant evaluation of venous access and implant location. In patients with a previous atrial switch operation and those with dextrocardia, right-sided venous access was chosen for better sheath orientation against the interventricular septum. Electroanatomical mapping of the right atrium, right ventricle, and His bundle region was obtained with the EnSite Precision (Abbott, Abbott Park, Illinois) or Carto (Biosense-Webster, Irvine, CA) mapping system in selected patients in order to delineate the conduction system course and facilitate lead implantation in complex anatomy. All locations with His bundle recordings were tagged and the pacing lead was conected to the mapping system to guide the implantation process in these cases as previously described[15].

For HBP, a standard C315 His sheath (Medtronic, Minneapolis, MI) was initially employed. A 3830 lead (Medtronic) was advanced and His bundle mapping was performed in an unipolar fashion. Unipolar electrograms obtained from the lead were displayed simultaneously in an electrophysiology recording system and in the pacing system analyzer. When a His deflection was identified, pacing at 5V at 1ms was performed

to assess His bundle capture using a 12-lead ECG displayed at a sweep speed of 100 mm/s. If the patient had a previous device and no escape rhythm was present, pacemapping was used to identify an adequate position based on the 12-lead ECG morphology. If the His-bundle area could not be reached with the C315 His sheath, a deflectable C304 SelectSite sheath (Medtronic) or other delivery tools (including pre-shaped stylet directed active fixation leads) were attempted at the discretion of the implanting physician. Once the His bundle area was identified, the pacing lead was rotated clockwise 5-10 times. Then, the sheath was withdrawn to the right atrium and sensing and pacing parameters were tested with a threshold goal of [?]2.5 V at 1 ms was considered optimal. If stable sensing and pacing parameters were confirmed, the sheath was removed and the suture sleeve was sutured to the underlying muscle. The use of a backup ventricular pacing lead was not routinely employed and left at the discretion of the implanting physician.

LBBAP was attempted using the technique previously described by Huang and collegues[16]. Briefly, after the His bundle area was identified, the delivery sheath was advanced 1.5-2 cm towards the RV apex and ventricular pacing was used to identify a "w" pattern in V1 with a notch at the nadir of the QRS. At this point 5-10 rapid rotations were applied to the lead and pacing parameters and the paced QRS morphology were evaluated. Additional rotations were applied when necessary to achieve LBB capture and contrast injections were used to check the degree of penetration into the septum. HBP was initially attempted in all patients except in those with previous atrial switch surgery, where the His bundle is not accesible from the systemic venous atrium, and those in whom the implanting physician expected a low probability of HBP success due to suspected distal conduction system disease. In those cases LBBAP was the primary pacing strategy.

Definition of successful HBP or LBBAP implant

HBP was defined as selective or non-selective capture as previoulsy described[17]. LBBAP was categorized as left bundle branch pacing (LBBP) or left ventricular septal pacing (LVSP). LBBP was defined according to the criteria described by Huang et al.[16] including: 1. RBBB pattern paced morphology; 2. Visualization of LBB potential; 3. Left ventricular activation time (LVAT) short and constant at high (5V) and low output (1V), or abrupt shortening at high output; 4. Transition from nonselective to selective LBBP during threshold testing. LBBP was considered present when at least 3 or more of these criteria were fullfilled. When LBBP criteria were not met but a deep septal position of the lead was evidenced with contrast (Supplementary video 1) and significant reduction in the final paced QRS width or a final paced QRS [?]130 ms was obtained, the implant was considered as LVSP

Statistical Analysis

Continous variables are presented as mean and standard deviation or median and interquartile range where appropiate. Categorical variables are presented as absolute frequencies. Comparison of normally distributed continous variables was performed using Student t test. Two tailed paired Student's t-tests were performed for continuous paired variables and Wilcoxon signed rank tests were used where appropriate. Tests were 2 sided, and a value of $P<0.05$ was considered statistically significant. All analyses were performed by using SPSS (IBM SPSS Statistics, Version 22.0, Armonk, New York, USA).

Results

A total of 20 consecutive patients from 4 different centers were included. Table 1 shows the baseline characteristics of the patients. Ten patients had complex forms of CHD, 9 had moderate defects, and 1 patient had a simple defect (Table 2). Ten patients had a previous device in place before attempting CSP. The reason for CSP in these 10 patients included previous ventricular lead dysfunction in 7 patients and pacing-induced cardiomyopaty in the remaining 3 patients. In 3 patients with RV lead dysfunction, extraction of the malfunctioning lead/s was also performed during the same implant procedure (patients #2, #6 and #12). In 5 patients, the malfunctioning leads (endocardial in 2 patients and epicardial in 3 patients) were abandoned during the procedure.

Implant procedure

Electroanatomical mapping was used during the implant in 6 patients: 4 with cc-TGA (1 with additional dextrocardia and 1 with a double switch operation), 1 with D-TGA and atrial switch operation (Senning) and in 1 patient with repaired VSD in order to identify the HB area and to delineate the anatomy (Figure 1).

Overall, acute implant success defined by HBP or LBBAP criteria was 100%. HB pacing was attempted in 14 patients (6 patients with cc-TGA, 3 Tetralogy of Fallot, 2 with a repaired VSD, 1 patient with D-TGA and a Rastelli correction, 1 with Ebstein's anomaly and 1 with AV canal) and was successfully achieved in 10 (71%). The 4 patients with unsuccessful HBP underwent LBBAP. In the remaining 6 patients LBBAP was used as the primary implant strategy. Strict LBB capture criteria were present in 5 patients and these patients were deemed to have LBBP while the remaining 5 patients were defined as LVSP with a significant reduction in final paced QRS width (figure 2). The time employed for the CSP lead implant widely varied ranging from 4-115 minutes with a mean of 31+-28 min. The mean total implant procedure duration was 126+-82 min.

A standard C315 His sheath was used first in all patients except one in which a C315S sheath was employed. Additional sheaths (C304 or others) were used in 10 patients (50%) due to difficulties in either localizing or achieving stable positions with the C315 His sheath. However, at the end, a C315 His or C315S sheath was used for definitive lead deployement in 14 patients (74%) and a C304 sheath was used for lead fixation in 4 patients. In 1 patient (D-TGA and large VSD corrected with a Rastelli surgery) a standard active fixation lead (Solia S53, Biotronik) was finally used with a previously preformed stylet to get access to the HB area resulting in a successful implantation. In patient #11 with a cc-TGA and a double switch operation a Attain Command 6250V-3D sheath was used for lead delivery. Table 2 summarizes the principal baseline characteristics and implant details for each patient.

Electrical parameters, programming and acute complications

The acute electrical parameters obtained at implant are represented in table 1. The mean QRS width in the entire cohort was significantly reduced from 144+-32 ms at baseline to 116+-16 ms during HBP or LBBAP, p=0.001 (Figure 4). The 5 patients with LVSP also significantly reduced QRS width from 141+-22 ms to 114+-15 ms, p=0.029 (Figure 2). The average penetration of the lead in the interventricular septum in the 5 patients with LVSP evidenced by contrast through the sheath was 7.4+-0.54 mm (baseline mean interventricular septal thickness in these patients was 8.2+-0.84 mm).

Patient #7 had a significant increase of LBB lead pacing threshold at day 4 post-implant evidenced by the sudden appeareance of bradycardia on remote monitoring. The initial implant procedure was challenging with multiple attempts of fixation due to poor lead stability in complex anatomy (D-TGA with Senning correction)(Figure 3). This patient underwent repositioning of the lead in the same location with excellent electrical parameters. A second back-up pacing lead was implanted in the subpulmonic ventricle and connected to a CRT-P generator. No other acute complications occurred in the study population.

Follow up

Median follow-up was 478 days (IQR 225-567). All patients showed stable electrical parameters at last follow-up. The ventricular pacing threshold remained stable from implant (0.85+-0.61V) to last follow-up (0.99+-0.68 V, p=0.38) with a maximum increase of 0.75V in patient #4. No complications were registered during the follow-up. Systemic ventricle systolic function showed a significant improvement in patients with a systemic LV (n=16 patients)(LV ejection fraction assessed by biplane Simpson's method: 51+-16% at baseline vs. 55+-17 at last follow-up, p=0.031), and also in patients with a systemic right ventricle (n=6 patients)(fractional area change: 39+-13% at baseline vs. 43+-15% at last follow-up, p=0.021) (Figure 4). NYHA class significantly improved during follow-up from 1.50+-0.51 to 1.10+-0.31 (p=0.008). Nine patients had symptomatic heart failure at baseline (NYHA class II) and improved to NYHA class I at last follow-up.

Discussion

This is the first case-series reporting on the safety and feasibility of CSP in unselected patients with a wide

range of CHD subtypes. Of note, 95% of patients included in our series had moderate or complex forms of CHD. Our results show that physiological pacing is feasible and safe in this subset of patients with a successful implant rate of 100% when considering both HBP and LBBAP, and 75% (15/20) when using strict criteria for LBBP. In the remaining 5 patients LVSP pacing with significant QRS narrowing could also be achieved. Of note, the systemic ventricle systolic function and NYHA class significantly improved during follow-up. Electrical parameters remained stable at last follow-up and only 1 patient required lead revision due to acute pacing threshold rise 4 days post-implant.

In recent years, CSP has emerged as the cornerstone of physiological pacing[1-5]. Several studies have demonstrated that HBP can reduce heart failure hospitalizations and can improve LVEF[1]. This potential benefit is greater for those patients with higher percentage of ventricular pacing and those with impaired LVEF at baseline; particularly, younger patients with a high burden of ventricular pacing[18]. In a series of 238 patients with CHD, the mean age at pacemaker implantation was 26 years IQR (13;42)[19]. Moreover, patients with CHD and chronic right ventricular pacing are at particularly increased risk of developing pacemaker induced cardiomyopathy. Recently, HBP has been shown to improve LVEF in chronically paced patients and pacing induced cardiomyopathy[5]. Our results show that CSP is feasible in chronically paced CHD patients with longstanding AV block and thus should be considered as a potential pacing strategy for this subset of patients with pacing induced cardiomyopathy.

Pacemaker implantation in patients with CHD can be challenging due to the baseline anatomical distortion and also due to the presence of prostethic materials introduced during the surgical corrections[8-11]. As a consequence, implant duration was prolonged with higher radiation exposure. As a reference, in one of the largest series of HBP published so far, mean implant duration was 70+-34 min for single or dual chamber pacemakers thus reflecting the complexity of the implant technique in patients with CHD[1]. The use of multiple sheaths in 50% of the cases also reflects the complex anatomy and the absence of tailored tools available. Moore et al.[12] have recently reported the safety and feasibility of CSP in 15 patients with cc-TGA showing an acute implant success rate of 85% with a median procedure time of 146 minutes (IQR 112– 212) and use of multiples sheaths in 27%. In comparison, our series with unselected CHD patients including more complex anatomies, shows that CSP is still feasible in a wide range of CHD defects.

Localization of the proximal conduction system in our cohort poses a challenge. Although simple defects are usually associated with minor variations, moderate and severe defects have characteristically significant variations in the conduction system disposition[20]. Electroanatomical mapping of the conduction system during implant in those patients with spontaneous intrinsic rhythm should be considered, especially in patients with complex anatomy and previous surgery. In patients with D-TGA and a prior atrial switch operation, only the left conduction system is usually accessible. In our 2 patients with D-TGA and a Senning correction we unsuccessfully tried to reach the proximal left bundle within the interventricular septum but ultimately accepted the distal portion of the left conduction system (left anterior fascicle)(Figures 3 and 5). Additional landmarks may be useful to localize the conduction system such as a calcified VSD patch from a previous membranous septum VSD closure (patient #4, cc-TGA + perimembranous VSD + dextrocardia), (Figure 6 and Supplementary video 2).

It is of interest that LBBP could be successfully achieved in the 2 patients with a D-TGA and previous atrial switch operation. A significant percentage of patients with an atrial switch operation are likely to develop future systemic RV dysfunction and may also need permanent ventricular pacing. Although biventricular pacing has been attempted in different CHD scenarios, the CS ostium is not usually accesible from the systemic venous atrium in these patients and thus the only chance for CRT in this setting is the surgical implantation of an epicardial lead in the systemic RV. Our 2 cases show that CSP can potentially be achieved after the atrial switch operation accesing the subpulmonic ventricle via the systemic venous atrium. In fact, this particular anatomic disposition allows direct access to the left conduction system as the subpulmonic ventricle is morphologically a left ventricle. In these 2 patients, we were able to clearly record and capture a left bundle potential (Figures 3 and 5). However, the effect of LBBAP on systemic ventricular synchrony requires further data as it relies on activation of the right bundle as well.

In conclusion, HBP and LBBAP are safe and feasible in patients with CHD and a permanent pacing indication despite challenging anatomy and advanced conduction system disease.

Limitations

This series is limited by the small number of patients. Larger studies with longer term follow-up would be desirable to corroborate our findings. The long-term safety of conduction system pacing needs further evaluation. Lastly, extractability of the leads implanted deep in the septum is currently unknown.

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Table 1. Baseline characteristics of the patients and procedure details

Age (mean±SD)	32 ± 17
Male sex (n, %)	9 (45)
Previous pacemaker (n, %)	10 (50)
Previous cardiac surgery (n, %)	15 (75)
LV systemic ventricle (n, %)	14 (70)
RV systemic ventricle (n, %)	6 (30)
LV systemic ventricle EF (%)(mean±SD)	51±16
RV systemic ventricle FAC (%) (mean±SD)	39±13
Systemic ventricle systolic dysfunction (n, %)	13 (65)
Baseline QRS width (mean±SD)	144±32
Baseline QRS>120 ms (n, %)	14 (70)
NYHA functional class (n, %) - I - II - III/IV	11 (55) 9 (45) 0
Baseline rhythm at implant (n, %) - normal AV conduction - 2nd degree AV block - complete AV block	3 (15) 2 (10) 15 (
Atrial arrhythmias (n, %)	10 (50)
Oral anticoagulation (n, %)	7 (35)
Serum creatinine (mean±SD)	0.76±0.21
INR (mean±SD)	1.3±0.5
General anesthesia (n, %)	4 (20)
Total procedure time (min)(mean±SD)	126±82
CSP lead implant time (mean±SD)	31±28
CSP sheath (n, %) - C315His - C304 - Other	14 (70) 4 (20) 2 (

No. attempts for CSP lead implant (mean±SD)	3.4±2.8
No. turns to screw the CSP lead (mean±SD)	14±6
CSP lead pacing threshold (V)(mean±SD)	0.85±0.61
CSP lead sensing (mV) (mean±SD)	9.8±9.2
CSP lead pacing impedance (Ohms)(mean±SD)	735±253
Final paced QRS width (ms)(mean±SD)	116±16
Total fluoroscopy time (min) (mean±SD)	27±30

LV: left ventricle; RV: right ventricle; EF: ejection fraction; FAC: fractional area change; INR: international normalized ratio; CSP: conduction system pacing

Table 2. Principal characteristcs of the patients and implant parameters.

Patient	**Age**	**CHD**	**Pacing indication**	**Previous cardiac surgery**	**Previous device**	**Baseline systemic ventricle systolic function (%)***	**Follow-up systemic ventricle systolic function (%)***	**Baseline ventricular rhythm**	**Baseline QRS width (ms)**	**CSP QRS width (ms)**	**CSP lead sheath+**	**CSP lead implant time (min)**	**Final pacing definition**
#1	53	ToF	Paroxysmal AV block	Classic ToF surgical repair	No	60	68	intrinsic	140	122	C315His	12	LVSP
#2	23	D-TGA + VSD	Post-surgical AV block	Rastelli	Endo PM	50	57	paced	192	128	Stylet-driven conventional RV lead	40	HBP
#3	13	cc-TGA	Complete AV block	No	No	64	60	intrinsic	100	116	C315S	40	HBP
#4	25	cc-TGA + VSD+ dextrocardia	Paroxysmal AV block	VSD closure	No	55	25	intrinsic	94	104	C304	43	HBP
#5	40	VSD	Post-surgical AV block	VSD closure	Endo PM	40	45	paced	144	98	C315His	20	LVSP

Patient	Age	CHD	Pacing indication	Previous cardiac surgery	Previous device	Baseline systemic ventricle systolic function (%)*	Follow-up systemic ventricle systolic function (%)*	Baseline ventricular rhythm	Baseline QRS width (ms)	CSP QRS width (ms)	CSP lead sheath+	CSP lead implant time (min)	Final pacing definition
#6	25	ToF	Post-surgical AV block	Classic ToF surgical repair	Endo PM	53	40	paced	170	121	C315His	35	LBB
#7	16	D-TGA	Post-surgical AV block	Atrial switch (Senning) + VSD closure + biologic pulmonary valve	Epi PM	20	18	paced	196	110	C315His	115	LBB
#8	11	Muscular VSD + CoAo	Post-surgical AV block	VSD closure	Endo PM	79	80	intrinsic	129	108	C315His	28	LVSI
#9	34	D-TGA	Paroxysmal AV block	Atrial switch (Senning)	No	26	28	intrinsic	138	138	C315His	45	LBB
#10	13	AV canal with cleft mitral valve	Post-surgical AV block	ASD closure (patch) + cleft mitral valve repair	Epi PM	62	80	intrinsic	116	104	C315His	10	LVSI

Patient	Age	CHD	Pacing indication	Previous cardiac surgery	Previous device	Baseline systemic ventricle systolic function (%)*	Follow-up systemic ventricle systolic function (%)*	Baseline ventricular rhythm	Baseline QRS width (ms)	CSP QRS width (ms)	CSP lead sheath+	CSP lead implant time (min)	Final pacing definition
#11	15	cc-TGA + VSD + tricuspid valve Ebsteinoid malformation	Post-surgical AV block	Double switch operation (Senning + Jatene)	Epi PM	60	62	paced	176	128	Attain Command 6250V-3D	45	LVSP
#12	56	AV canal with cleft mitral valve	Post-surgical AV block	Mitral and tricuspid valve repair + ASD repair	Epi PM	69	71	paced	168	118	C315His	17	LBB
#13	59	VSD + pulmonary stenosis	Complete AV block	VSD closure + pulmonary stent	No	47	45	intrinsic	138	140	C304	5	LBB
#14	18	cc-TGA	2nd degree AV block	No	No	50	55	intrinsic	118	140	C304	5	HBP
#15	64	Ebstein's anomaly	2nd degree AV block	No	No	51	55	intrinsic	90	90	C315His	4	HBP

Patient	Age	CHD	Pacing indication	Previous cardiac surgery	Previous device	Baseline systemic ventricle systolic function (%)*	Follow-up systemic ventricle systolic function (%)*	Baseline ventricular rhythm	Baseline QRS width (ms)	CSP QRS width (ms)	CSP lead sheath+	CSP lead implant time (min)	Final pacing definition
#16	27	AV canal + partial anomalous pulmonary venous return + coarctation of the aorta + heterotaxy (polysplenia)	Post-surgical AV block	AV canal + coarctation + pulmonar venous return repair	Endo PM	55	55	paced	184	122	C315His	5	HBP
#17	38	cc-TGA	Complete AV block	No	No	34	37	intrinsic	160	126	C315His	NA	HBP
#18	53	ToF	AV node ablation	Classic ToF surgical repair	No	36	50	intrinsic	162	82	C315His	NA	HBP
#19	24	cc-TGA	Congenital heart block	No	Epi PM	46	54	intrinsic	158	98	C315His	NA	HBP

Patient	Age	CHD	Pacing indication	Previous cardiac surgery	Previous device	Baseline systemic ventricle systolic function (%)*	Follow-up systemic ventricle systolic function (%)*	Baseline ventricular rhythm	Baseline QRS width (ms)	CSP QRS width (ms)	CSP lead sheath+	CSP lead implant time (min)	Final pacing definition
#20	26	ToF	Post-surgical AV block	Classic ToF surgical repair	Endo PM	39	43	intrinsic	110	112	C304	65	HBP

* Systemic ventricle systolic function was assessed by biplane Simpson's method in patients with a systemic LV and using fractional area change in patients with a systemic right ventricle.

+ Final sheath with which the lead was implanted.

CHD: congenital heart disease; EF: ejection fraction; HBP: his bundle pacing; CSP: conduction system pacing; LBBAP: left bundle branch area pacing; ToF: tetralogy of Fallot; D-TGA: D-transposition of the great arteries; VSD: ventricular septal defect; RV: right ventricle; cc-TGA: congenitally corrected transposition of the great arteries; ASD: Atrial septal defect; NA: not assessed; PM: pacemaker; Endo: endocardial; Epi: epicardial.

Figure legends

Figure 1 . Electroanatomical map of patient #4 with congenitally corrected transposition of great vessels and dextrocardia performed with a multipolar catheter (HD Grid, Abbott). Green tags correspond to His bundle recording with adequate pacing thresholds. The lower panel shows the His bundle electrograms recorded with the HD Grid catheter. SVC: superior vena cava; IVC: inferior vena cava; CS: coronary sinus; SPV: subpulmonic ventricle.

Figure 2 . Figure 2. Baseline (left) and final paced 12 lead ECG (right) in the 5 patients with left ventricular septal pacing (LVSP). Sweep speed 25 mm/s.

Figure 3 . Patient #7 (D-TGA status post Senning atrial switch operation). Panel A and B show the right (RAO) and left anterior oblique (LAO) fluoroscopic views of the final lead position. The left bundle branch pacing (LBBP) lead is indicated with an asterisk. The other endocardial ventricular lead was implanted as a back-up pacing lead. Panel C shows the electrogram recorded from the pacing lead tip corresponding to a large anterior fascicle potential and a non-selective LBBP beat. Panels D and E show the baseline epicardial paced ECG and the final LBBP 12-lead ECG, respectively.

Figure 4 . A) mean systemic left ventricular (LV) ejection fraction at baseline and at last follow-up measured by biplane Simpson's method in patients with a systemic LV. B) mean systemic right ventricle (RV) fractional area change in patients with a systemic RV. C) evolution of NYHA class from baseline to last follow-up.

Figure 5 . Patient #9 (D-TGA status post Senning atrial switch operation). Panels A and B show the electroanatomical maps of the PVA (purple) and SVA (cyan) performed with the CARTO system with yellow tags representing His bundle electrograms recorded in the PVA. Panels C and D show the AP and LAO views

of the patient with the 3830 lead implanted in the left anterior fascicle area in the subpulmonic ventricle (red asterisc). Yellow tags represent His-bundle area extrapolated from the electroanatomic maps. Panel D shows a spontaneous beat with the anterior fascicle potential (red arrow) registered at the tip of the 3830 lead followed by a paced beat showing selective capture of the left bundle. PVA: pulmonary venous atrium; SVA: systemic venous atrium; Ap: anteroposterior view; LAO: left anterior oblique view; SVC: superior vena cava; IVC: inferior vena cava.

Figure 6 . Patient #4 with congenitally corrected transposition of great vessels and dextrocardia. Panels A and B showing left (LAO) and right anterior oblique (RAO) fluoroscopic views of the implanted leads. Note that a radioopaque line (red asterisk) can be seen at the tip of the ventricular lead in panel B corresponding to the VSD calcified patch that served as an anatomical reference for lead implantation. Panel C shows the His electrogram (red arrow) recorded from the lead tip (unipolar) and non-selective His bundle-pacing. Panels D and E show the native QRS and final paced QRS with non-selective HBP.

Figure 1.

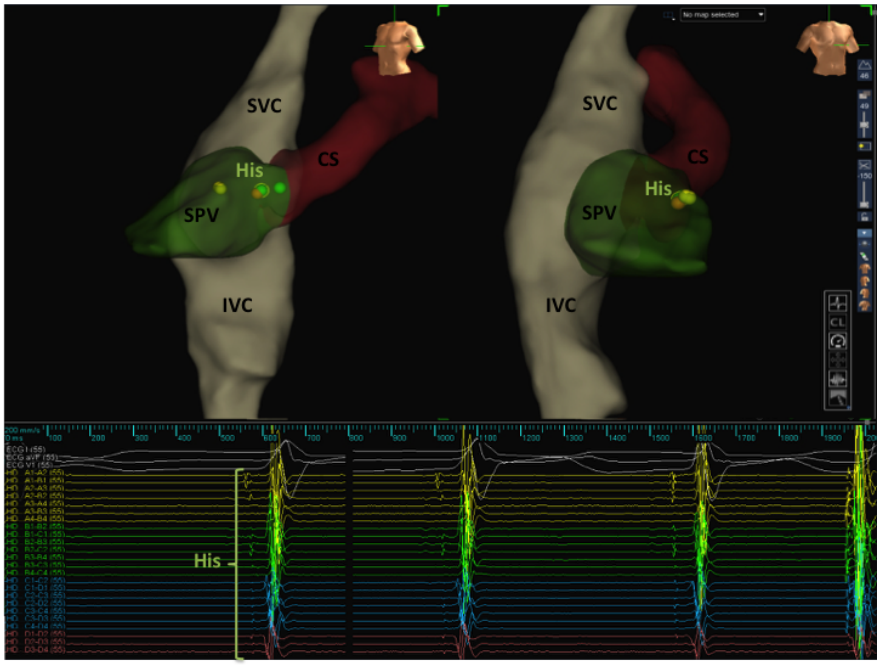
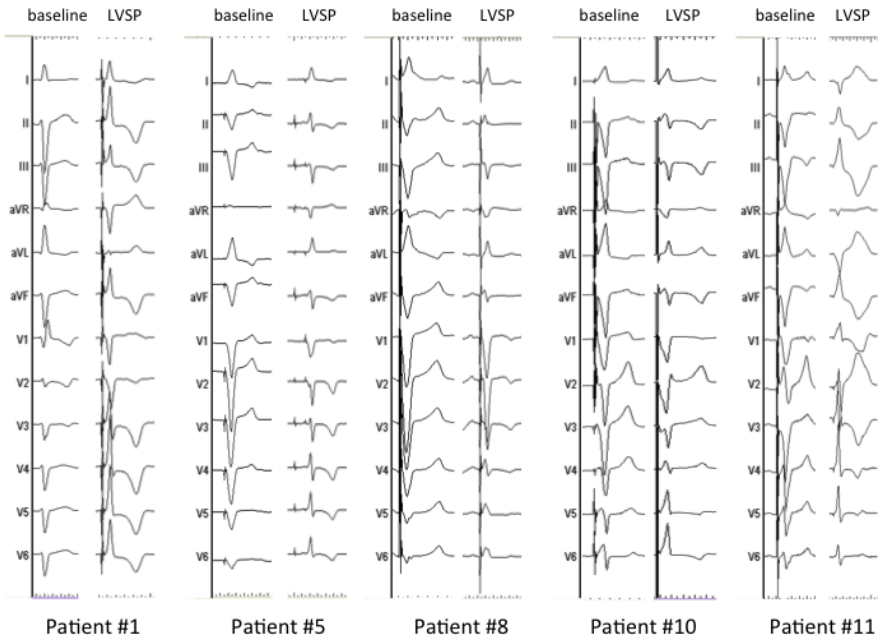


Figure 2.



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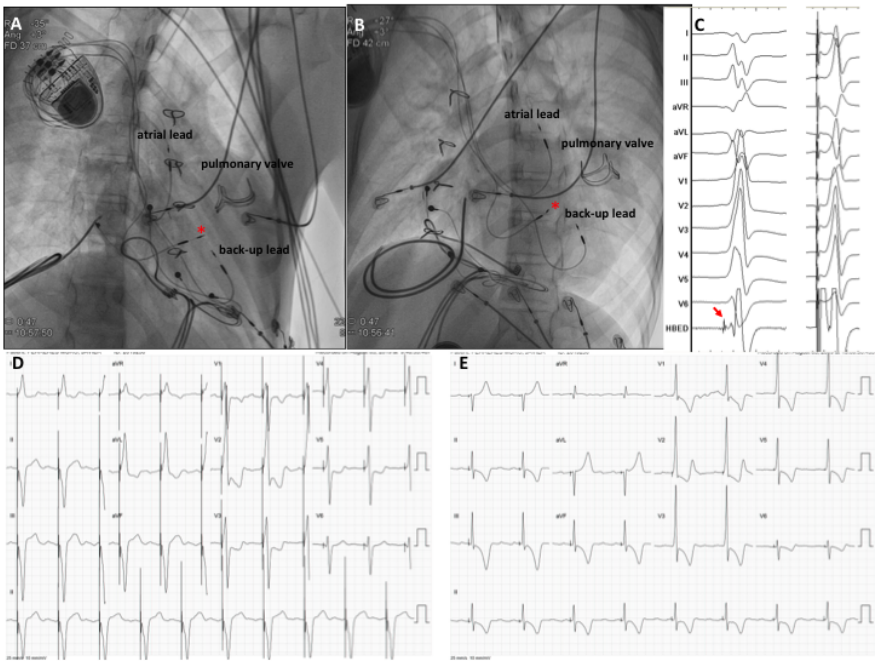

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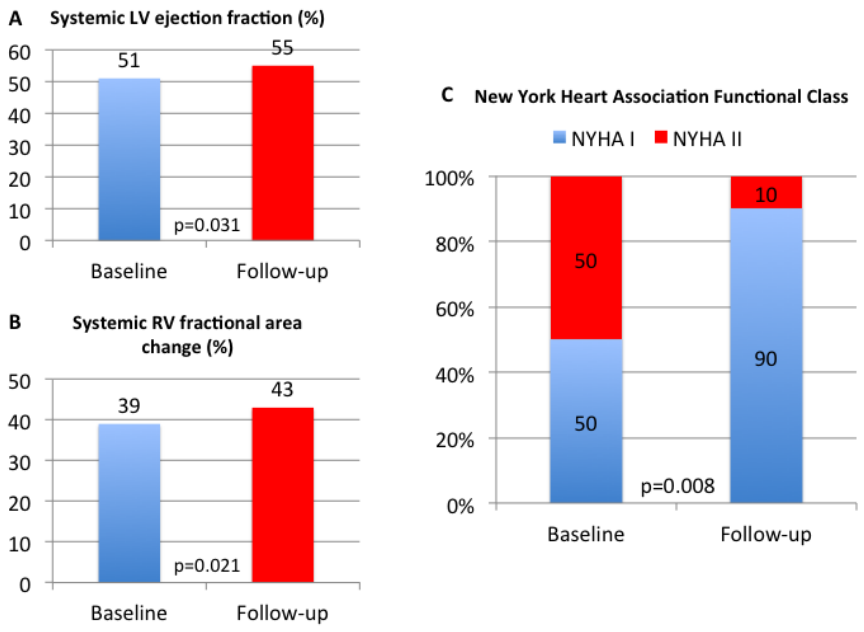

Figure 5.

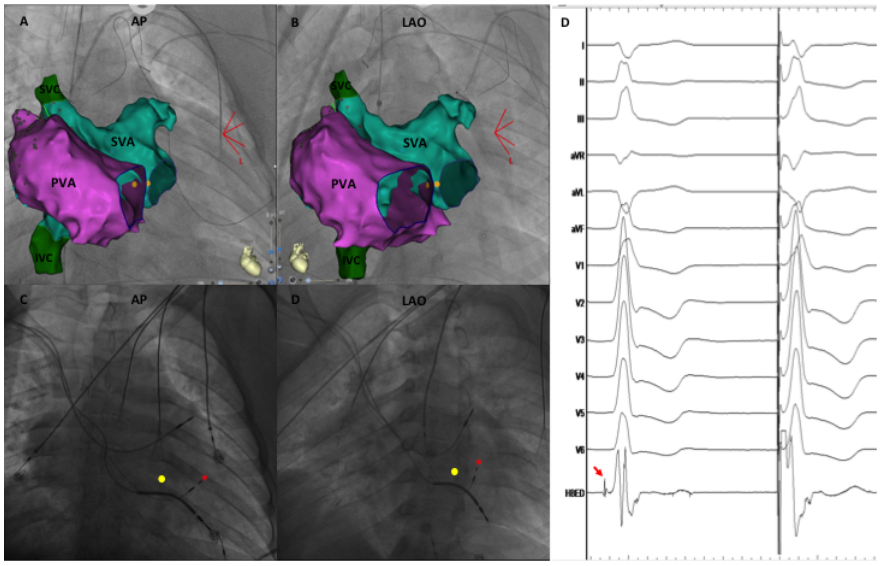

Figure 6.