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Anatomical variations in Coronary Venous Drainage: Challenges and Solutions in Delivering Cardiac Resynchronisation Therapy

Short title: Coronary venous anatomical variations and CRT implantation

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ABSTRACT

Aims: To investigate the abnormalities of the coronary venous system in candidates for cardiac resynchronization therapy (CRT) and describe methods for circumventing the resulting difficulties.

Methods: From 4 implanting institutes, data of all CRT implants between October 2008-October 2020 were screened for abnormal cardiac venous anatomy, defined as an anatomical variation not conforming to the accepted 'normal' anatomy. Patient demographics, procedural detail and subsequent left ventricle (LV) lead pacing indices were collected.

Results: From a total of 3548 CRT implants, 15 (0.42%) patients (80% male) of 72.2±10.6 years in age with a LV ejection fraction of 34±10.3% were identified to have had an abnormal cardiac venous anatomy over the study period. There were 13 cases of persistent left side superior vena cava (pLSVC), 5 of which had coronary sinus ostium atresia (CSOA) including 2 with an 'unroofed' coronary sinus (CS); 1 patient had a unique anomalous origin of the CS and 1 patient had an isolated CSOA. In total 14 patients (60% repeat attempt) had successful percutaneous implant under general anaesthesia (46.7%) via the cephalic vein (59.1%), using the femoral approach (53.3%) for levophase venography and/or pull-through, including 1 case of endocardial LV implant. Pacing follow-up over 37.64±37.6 months demonstrated LV lead threshold between 0.62-2.9 volts (pulsewidth 0.4-1.5 milliseconds) in all cases; 5 patients died within 2.92±1.6 years of successful implant.

Conclusion: CRT devices can be implanted percutaneously even in the presence of substantial abnormalities of coronary venous anatomy. Alternative routes of venous access may be required.

Key Words: Persistent left superior vena cava; Anomalous coronary sinus; Cardiac Resynchronisation Therapy; Subclavian Vein

Condensed abstract

Of the 3548 patients requiring cardiac resynchronisation therapy (CRT) across 4 centres, 15 (age 72.2±10.6 years; 80% male) had abnormal coronary venous anatomy. Thirteen patients had a persistent left side superior vena cava, of which 5 had coronary sinus ostium atresia including 2 cases of an 'unroofed' coronary sinus; 1 patient had a unique anomalous coronary sinus origin. Fourteen patients subsequently had successful percutaneous implant using the femoral approach (53.3%) for mapping and/or 'pull-through'; 1 required endocardial LV implant with life-long anti-coagulation. Pacing follow-up over 37.64±37.6 months was satisfactory. Percutaneous CRT implant in abnormal anatomical variations is feasible.

INTRODUCTION

Cardiac resynchronisation therapy (CRT) has become a cornerstone of the management of heart failure (HF) (1)(2)(3). The rate of successful implantation is recognisably higher in experienced hands whilst refinement of techniques and tools have contributed to a falling failure rate (4). Transvenous left ventricle (LV) lead implant failure however can occur in 3.6% of cases (4), undermining the benefits of this therapy. Although surgical epicardial lead placement is available for these cases, the patient group requiring CRT is subject to a high peri-operative morbidity and mortality when undergoing major cardiac surgery (5.6%) (5). A percutaneous approach is preferable, but adverse venous anatomy including an anomalous course of the coronary sinus (CS), is a major contributor to implant failure (4). The best recognized variant is the presence of a left superior vena cava (SVC) which drains via the coronary sinus to the right atrium and may or may not be associated with a right SVC (6).

METHODS

Between October 2008 – October 2020, all cases of CRT implants in patients with abnormal venous anatomy were identified from a group of 4 associated centres performing complex pacing. The anatomical variation was defined as abnormal if the anatomy did not conform to the structure of the CS ostium lying in the atrioventricular groove providing a route of venous return to the right atrium close to the inferior margin of the tricuspid annulus. This includes: a persistent left SVC, anomalous CS drainage, occlusion of the CS ostium and unroofed CS. Implants were performed by high-volume operators. Patient demographics, procedural data and pacing follow-up information of the LV lead were recorded. Methods used by the operators to circumvent the difficulties arising from these anatomical challenges were reviewed and highlighted. For patients with normal anatomy, a standard procedure involving the cephalic (7), axillary or subclavian access was performed based on the discretion of the operator. Continuous variables are presented as a mean ± standard deviation and categorical variables conveyed as a number and percentage. The study proposal was approved by the local Research Ethics Committee and complies with the principles of the Declaration of Helsinki. All patient information is anonymised.

Femoral pull-through

The femoral pull-through technique has been previously described. The femoral pull-through technique has previously been described in detail (8)(9). Using a 14-french sheath in the femoral vein, and a long delivery system, a deployable left ventricle lead is positioned in a suitable coronary vein. Via the same 14-f sheath, a J-tip guidewire is

passed to the right superior vena cava where it is snared by a Gooseneck snare (Medtronic, MN, USA) from the superior access (14-french sheath). This end of the guidewire is then pulled out the subclavian access point, the guidewire is pulled taut and is used as a rail, over which a SL0 sheath (Abbott, IL, USA) is advanced from the superior access to emerge out through the femoral sheath. Once this sheath is exposed out of the body at the femoral end, the introducer and guidewire are removed, permitting the IS-connector of the LV lead to be inserted into the mouth of the sheath where it is fixed using a silk suture. The SL0 with the IS-connector is then pulled upward, the rest of the lead following it to emerge from the subclavian access in the normal manner to connect to a generator in a standard location at a left superior subcutaneous pocket.

RESULTS

In the study period, 3548 CRT implants or upgrades were performed at the contributing centres. A total of 15 patients (0.42%) aged 72.2±10.6 years (80% male) with body mass index 29.2±3.3 kilograms/metre^2 and left ventricle ejection fraction of 34±10.3% were found to have important anomalies of the venous system, and included in this report (**table 1**). Of these, 7 patients had ischaemic cardiomyopathy, 8 were hypertensives, 4 diabetics and 6 had previous cardiac surgery including prosthetic valve implant in 3 cases.

There were a variety of anatomical variations: persistent left side superior vena cava (PLSVC) in 13 cases of which 5 were associated with coronary sinus ostium atresia (CSOA) and 1 had a single large draining cardiac vein **(table 1)**. From the 5 PLSVC + CSOA cases, 2 were 'unroofed' with the CS draining into the left atrium (LA), whilst the other 3

had CS drainage via the PLSVC including 1 with an associated small radical vein linking to the RA. Of the 2 non-PLSVC cases, 1 had an isolated CSOA with drainage from small radicals in to the right atrium (RA) and the other had a unique anomalous origin of the CS from the lateral RA **(figure 1; video 1)**.

In total, 14 patients (93.3%) had a successful CRT implant (66.7% CRT-defibrillator) of which 9 (60%) were repeat attempts following previous failure. In the single unsuccessful case, LV lead placement was not attempted/abandoned as the left ventricular function was moderately impaired and the risk of thromboembolism from implanting this lead in an unroofed CS outweighed the benefit; a dual chamber implantable cardioverter defibrillator (ICD) was accepted. General anaesthesia (GA) was utilised in 46.7% of cases to position a total of 44 leads via the cephalic vein (59.1%), requiring 26.9±14.7 minutes of fluoroscopy in a procedure lasting 171.8±61.3 minutes. During follow-up, 2 patients required further procedures: 1 underwent complete system extraction due to infection 18 months after implant and the other required LV lead pull-back to treat phrenic nerve stimulation 1.1 months following implant. To date, 5 patients (33.3%) have died within 2.92±1.6 years of successful CRT implant whilst the remainder have been followed for 4.27±3.2 years from the date of successful implant.

Implant techniques

In one patient with cardiac venous drainage via a PLSVC to the left atrium, the LV lead was not implanted due to the calculation that the risk of stroke outweighed the potential benefit of CRT as the LVEF was relatively preserved at 40%. In all other patients, the LV lead was implanted successfully including another patient with cardiac

venous drainage to the left atrium in whom a standard technique via the PLSVC was used and lifelong warfarin therapy was initiated **(figure 2; video 2)**.

A small proportion of patients with PLSVC had the CRT implanted via the left superior vena cava (n=4/13; 30.8%) **(figure 3)**; the remainder had an associated right SVC through which the implant was performed, including the 3 patients who had an entirely right sided CRT implant (n=3/15; 20%). One patient underwent implantation of the LV lead via the PLSVC from the right superior access and the other leads of the CRT from the left superior access via the right SVC **(figure 4)**.

Femoral access was utilised in 8 cases for imaging the cardiac venous system by coronary arterial injection and follow-through (levophase venography; n=7), and to snare and/or pull-through leads in 3 patients. In these 3 cases, the LV lead implant was dependent on the femoral access: one had CSOA needing endocardial LV lead placement via a transeptal puncture from the femoral vein and the other two required femoral snaring of a guidewire that was navigated via the PLSVC to the right SVC. In one of these 2 cases, balloon dilatation of the radical vein ostium using the snared guidewire (via the small PLSVC) as a railroad was performed, which allowed LV lead deployment via the femoral vein and subsequent lead pull-through to the superior access point **(figure 5; video 3)**. In the other patient the snared guidewire (via femoral) provided a sturdy railroad for CS delivery system from the subclavian access to the acutely angulated CS ostium **(figure 6).**

Venography to image the venous system was performed in all cases via direct subclavian injection (33.3%), direct coronary sinus injection (20%) and levophase CS venography (46.7%).

The pacing follow-up occurred in all patients for a period of 37.64±37.6 months to date. The LV lead pacing threshold ranged between 0.62 – 2.9 volts at 0.4 – 1.5 milliseconds pulse-width with impedance of 326 – 1234 ohms **(table 1)**.

DISCUSSION

This report demonstrates that CRT can be delivered using exclusively percutaneous, transvenous methods in most cases even in patients with abnormal coronary venous anatomy. This implies that pre-procedure imaging of the venous system is not required as a means of patient selection for percutaneous CRT.

Visualisation of the venous anatomy is integral to CRT implant. Direct visualisation of the veins with venography is ideal but not always possible. Levophase CS venography was utilised in most of the cases within this series. Through this method, location of the CS ostium (therefore venous drainage), existence of a connecting radical vein and the identify of a PLSVC can be confirmed (10)(11). This permits planning of the procedure including direct contrast venography of the targeted veins to delineate the course of the vessels. Often repeat procedures are required; the initial procedure commonly results in identification of the abnormal anatomy and mapping of the vasculature whilst the second procedure results in implant following adequate planning.

A large proportion of patients within this series had experienced a previous CRT implant failure (60%) due to their unusual anatomy. This would represent an overall CRT failure

rate of <1% in high-volume centres (8); all these patients had successful implant on repeat attempt. The cause of implant failure at the initial procedure is likely multi-factorial. In most cases the abnormal anatomy is an unexpected finding during the procedure and therefore there is a lack of operator preparation. Experienced operators are much more likely to be able to overcome the challenges than inexperienced operators. They will be familiar with a wide range of equipment and techniques including angioplasty (11). Angioplasty of the coronary venous system (venoplasty) can provide multiple benefits including dilatation of narrowings to facilitate access and deployment (12), and also for anchoring to support catheter engagement (13)(14). Familiarity with these techniques is essential to reap the benefits whilst preventing complications. Although coronary interventionists are most familiar with this technique and tools, within our series the coronary venous intervention was performed by electrophysiologists. This suggests that having the experience and knowledge of the tools and techniques is more significant than the profession of the operator (11)(15).

A PLSVC anomaly has been observed in 0.3% of the general population (16) and is the most common anatomical variation noted in our series. It is the remnant of the embryonic left anterior cardinal vein which connects caudally to the left duct of Cauvier and subsequently the left horn of the sinus venosus (which matures into the CS). With embryological development, it regresses to become the vein of Marshall, which is seen as a small branch arising from the proximal CS in the majority of the population; if it persists, a PLSVC ensues (17). The PLSVC visualised at the junction with the RA is inadvertently described as a dilated CS. The actual CS is a separate branch of this large

vein as illustrated in our series **(figures 3 &7). T**he dilated portion probably derives from the left duct of Cauvier.

A PLSVC can occur with and without CSOA (10). In the absence of CSOA, the pre-dominant difficulty for lead implant arises from the acute angulations created by the left sided drainage (18). There are several corners to navigate: the subclavian-PLSVC junction (left sided implants), the bend to access the RV and in some cases, the tight angle to access the CS branches. These can be overcome with standard CRT delivery tools in experienced hands (18). Otherwise, catheters with acute 'hooks' can be used to navigate a wire; sub-selector and coronary catheters can be useful for this. When a right SVC is also present, switching the implant to the opposite side can present a more favourable angulation for lead implantation as experienced in 3 cases within our series **(figure 7)**.

The femoral approach can be a useful strategy in overcoming CSOA, as demonstrated in 3 of our patients who had a failed superior attempt. Femoral access is commonly reserved for the most complex cases and with good outcomes (8). It was used in our series for the isolated CSOA case as attempts to locate the CS ostium or a PLSVC were futile. The femoral approach was used to position an endocardial LV lead (active fixation) via a transeptal puncture, and then to perform a subclavian 'pull-through' of the IS-1 LV lead connector to the pectoral region (9). This technique is feasible and straightforward for electrophysiologists as demonstrated in a small case series (19). In our case, the pacing indices remained satisfactory for 18.6 months until the patient's demise from progressive heart failure, demonstrating stability.

The exposure of a foreign surface to the systemic circulation presents a risk when leads are placed via a trans-septal route or when they are placed in a coronary venous system that drains to the left atrium. Vitamin-K-antagonists have a satisfactory record in preventing strokes in patients with prosthetic valves in the systemic circulation, whereas direct oral anticoagulants fail to prevent embolic events in this group (20). We use and recommend chronic anti-coagulation with vitamin-K-antagonists in all patients with a lead exposed to the systemic arterial circulation to reduce the risk of clot embolization which is demonstrably higher in this group (21).

We encountered 3 other cases of CSOA with PLSVC. In these cases, the CS can be roofed or unroofed. It is important to determine this difference because in an unroofed CS the venous drainage concludes in the LA. This has the potential for clots to embolise with catastrophic results. Venous drainage into the LA can be identified using venography to ascertain the exit point of contrast into the atria. This can be difficult but in the LAO view, drainage directing towards the left indicates a LA drainage**.** It is feasible to position a LV lead in an unroofed CS, but it has long-term implications as blood flowing around a lead in this position flows to the systemic arterial circulation so thrombus forming on, and embolising from this location has the potential to cause a stroke; anti-coagulation with a vitamin-K-antagonist is advocated in this scenario.

In the patients with CSOA but without venous connection to the LA (roofed CS), the venous drainage occurs retrogradely via the PLSVC to the left subclavian or brachiocephalic vein (22). Implanting a LV lead via the PLSVC proved possible in all the cases we have encountered but required work to overcome the angulations.

Alternatively, pinpointing a venous channel draining to the right atrium from the CS body may provide the opportunity to dilate the channel to a size sufficient to accommodate a lead using techniques adapted from with coronary angioplasty. It is best approached from the femoral vein as the optimal angle of engagement is from the inferior approach. Following dilatation, the delivery sheath may or may not engage for lead delivery. Using the PLSVC as a route for navigating the coronary guidewire to the right SVC where it can be snared to provide a resolute monorail for LV lead delivery, is another option (8); occasionally a deployable LV lead can be used as an anchor to advance the guidewire if further backup support is required (13).

LIMITATIONS

This series was based on a small number of centres, none of which specializes in paediatric cardiology or in patients with grown-up congenital heart disease. It does not address every abnormality of venous anatomy and specifically excludes those encountered in the context of complex congenital heart disease.

CONCLUSION

Cardiac resynchronisation therapy devices can be implanted using percutaneous transvenous methods alone in a majority of patients with abnormal coronary venous drainage. This approach is safe and efficient, though less safe and efficient than in patients with a conventional anatomy.

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Table 1: Patient demographics and procedural details

Patient	Age (years)	Comorbidities	Anatomical variation	LV lead access vein	Procedures required	How was implant successful?	Implant procedure duration (minutes)	Implant procedure fluoroscopy duration (minutes)	LV threshold (Volts)	Pulse duration (milliseconds)
1	58	HTN, NICM	Anomalous CS ostium at the RA appendage	Left subclavian	3	Evolution sheath used to extract the ICD lead for venous access. The anomalous CS ostium was accessed using an AL2 catheter. Once accessed, a standard LV implant was performed.	221	52	1.6	0.8
2	75	IHD, CABG	Unroofed CS with CSOA + pLSVC	Left axillary	2	Standard LV lead implant using a sub-selector to access a suitable vien; life-	174	21	2.25	1.5

						long anti-coagulation commenced				
3	80	IHD, DVT	pLSVC	Left cephalic	2	Implanted via left SVC with standard equipment	85	15	0.8	1
4	55	NICM	CSOA + pLSVC	Right cephalic	2	The LV lead was implanted lead via right cephalic vein (better angulation to access the pLSVC) and the IS-1 connector tunnelled to the left pocket.	209	31	1	1
5	74	HTN, IHD, CABG+AVR	CSOA + pLSVC	Right axillary with femoral pull-through	2	Femoral access used to access the CS via a radical vein. A 0.014 was guidewire passed via the CS and pLSVC to the RA where it was snared to provide a railroad for venous	243	43	1.25	1

						angioplasty to be performed at the radical vein ostium. A CS delivery system was then engaged to deliver a LV lead.				
6	86	HTN, T2DM, AF	pLSVC	Left subclavian	2	Conventional implanted via right SVC	116	27	1	0.4
7	82	HTN, IHD, CABG	CSOA only with radical vein connection to RA	Right subclavian with femoral pull-through	2	Femoral access to perform transeptal puncture and implant left ventricle endocardial lead with standard lead pull-through to superior access	228	32	1	0.4
8	70	IHD, AVR	pLSVC	Left axillary	2	Tight angulation of the CS ostium: navigated a 0.014 guidewire via the pLSVC to the RA where it was snared from the	161	27	1.75	1

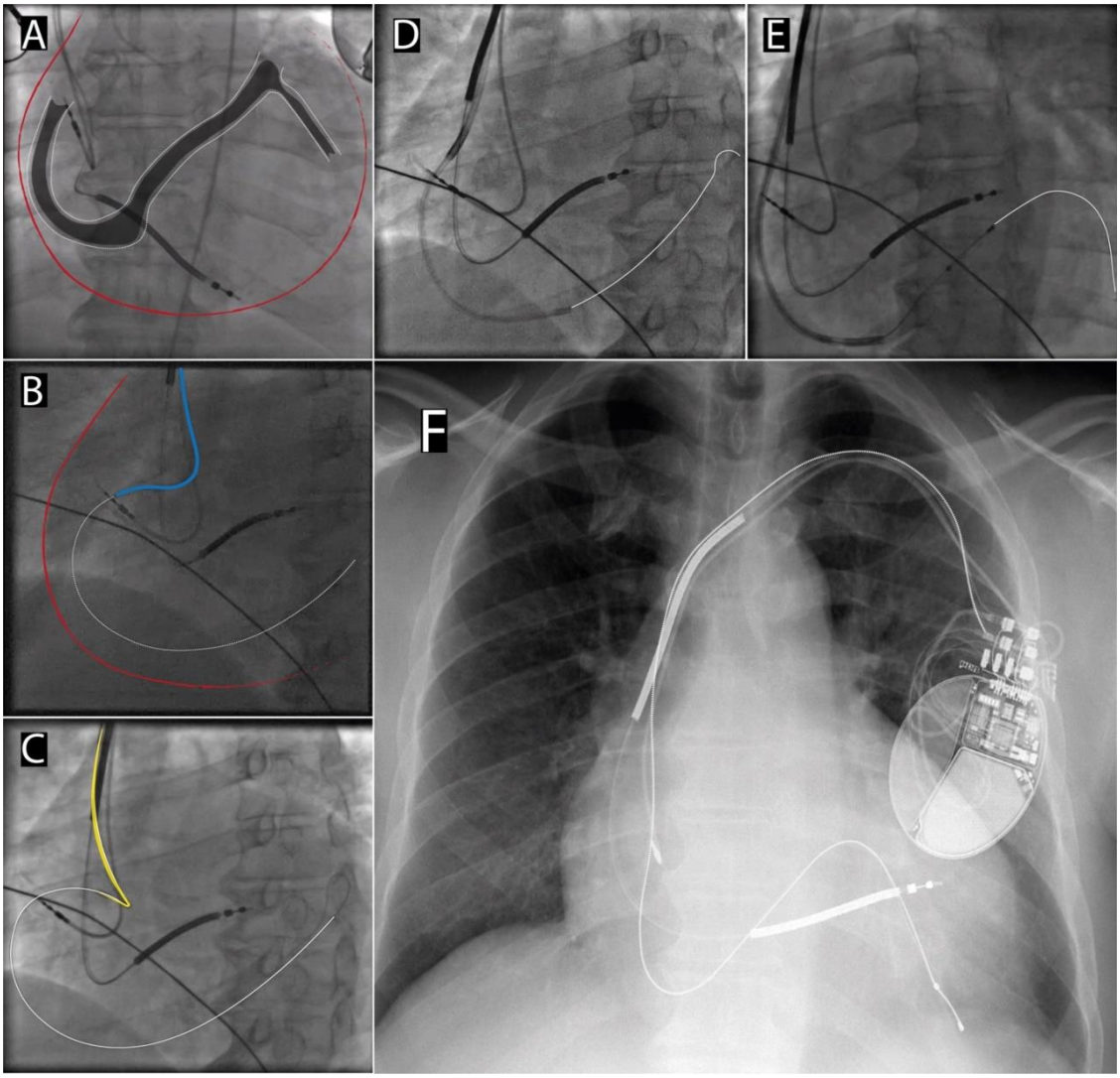
						femoral access for railroading the guideshe ath in to CS and delivering the LV lead.				
9	64	T2DM, HTN, IHD	CSOA + pLSVC	Left cephal ic	1	LV lead implante d via the pLSVC (using standard techniqu e), which was draining the cardiac venous system to the left subclavia n vein; there was CSOA.	190	45	1	1
10	82	HTN, severe MR	pLSVC	Right cephal ic	1	Switched to right side implant for better angulatio n	182	-	-	-
11	79	HTN, T2DM, IHD	Single large poster o-lateral vein drainin g the left atrium + pLSVC	Left cephal ic	1	Standard delivery of LV lead in the single large LV vein (only target)	70	5	0.7	1
12	70	AF, NICM	Unroof ed CS with CSOA + pLSVC	Not requir ed	1	No LV lead implante d at this stage –	252	17	No LV lead	-

						the LV function was moderately impaired and therefore the risk of a LV lead in an unroofed CS outweighed the benefit. It is a feasible option if needed in the future with lifelong anti-coagulation				
13	78	AF, NICM	pLSVC	Right subclavian	2	LV lead implant via the pLSVC unsuccessful due to tight angulation accessing the coronary venous system; right sided implant was performed via the right SVC (no communication between the two	-	-	0.62	0.4

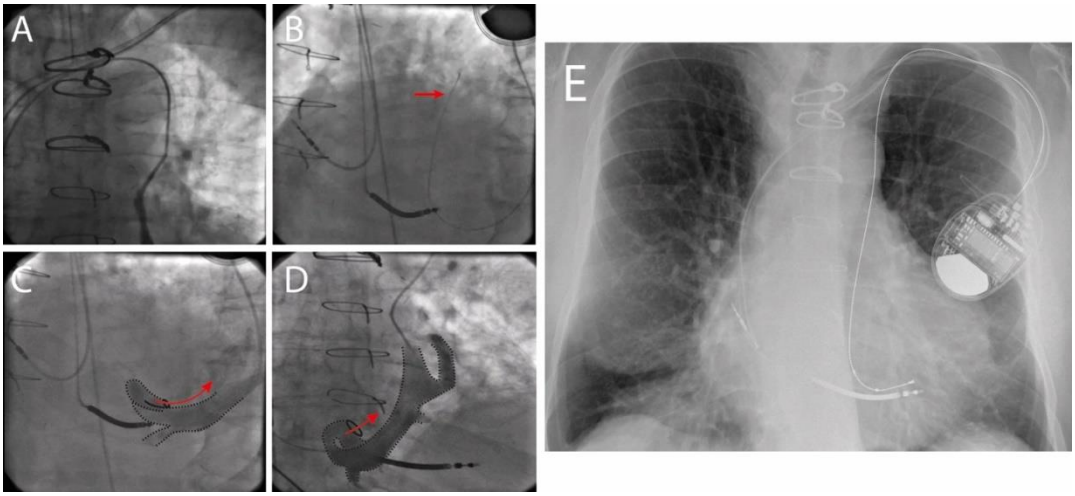
						SVC)				
14	75	HTN, T2DM, IHD, DVT, CABG	pLSVC	Left subclavian	1	Standard CS implant via the left SVC	-	-	2.9	1
15	52	ASD closure, LV non-compaction, NICM, IHD	pLSVC	Right subclavian	1	Standard CS implant via the right SVC	102	8	1	0.4

***Abbreviations**:* CS=coronary sinus; CSOA=coronary sinus ostial atresia; CV=cardiovascular; SVC=superior vena cava; MR=mitral regurgitation; IHD=ischemic heart disease; CABG=coronary artery bypass graft; AR=aortic valve regurgitation; AVR=aortic valve replacement; ASD= Atrial septal defect; NICM=non-ischaemic cardiomyopathy; DVT=deep venous thrombosis; T2DM=type 2 diabetes mellitus; AF=atrial fibrillation; LA=left atrium; RA=right atrium; HTN=hypertension; pLSVC=persistent left superior vena cava; AL2=Amplatz left-2; CS=coronary Sinus; ICD=implantable cardioverter defibrillator; LV=left ventricle; pLSVC=persistent left superior vena cava; SVC=superior vena cava

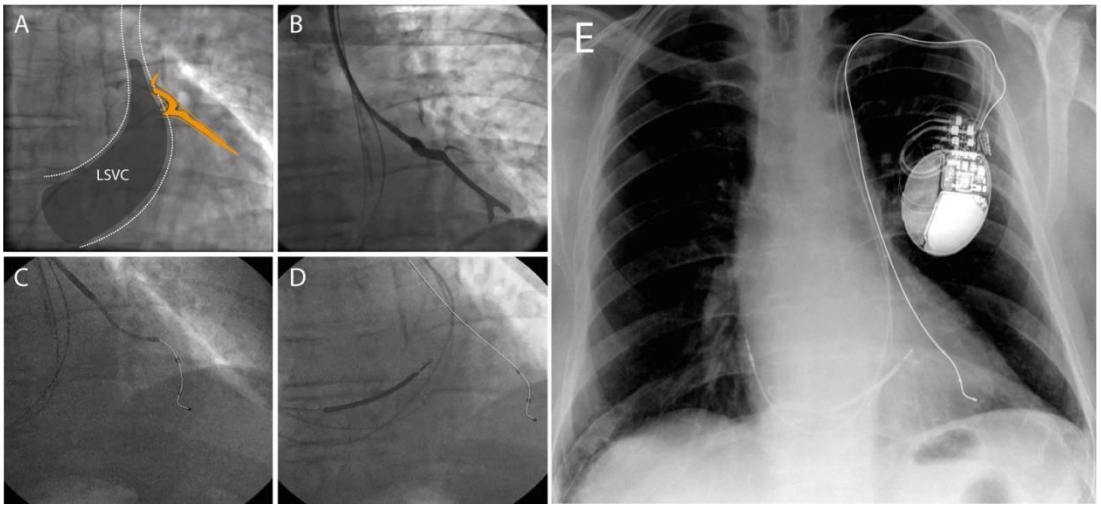
Figure 1: Patient 1 with an anomalous coronary sinus origin



A) Levophase venography confirmed that the coronary venous drainage occurs via the coronary sinus with the ostium situated in the high-lateral right atrium. The cardiac border is emphasised in red. **B)** Left anterior oblique (LAO) view: Engagement of the coronary sinus (CS) ostium was challenging but successful with an Amplatz Left-2 catheter (blue) and a Terumo wire (white line). **C)** LAO view: The Terumo wire facilitated CS engagement with a delivery sheath (yellow). **D)** A sub-selector was passed deeply in to the coronary sinus with back-up support from the delivery sheath. **E)** The left ventricular lead was successfully delivered to a suitable postero-lateral branch for CRT.
Figure 2: Images of Case 2



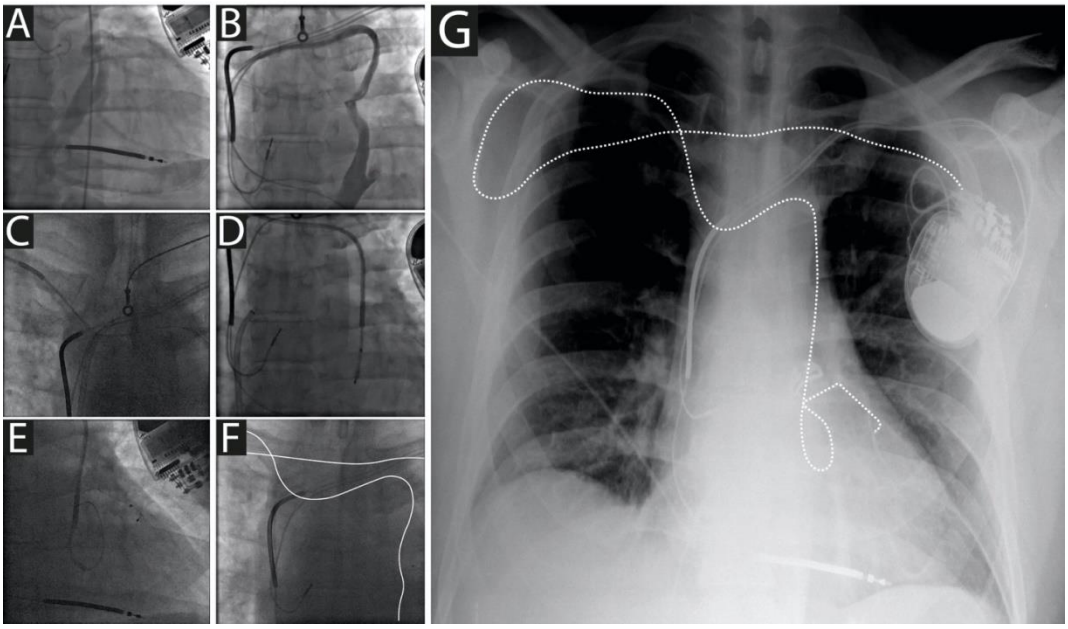
Using levophase venography the left superior vena cava was identified, which was accessed for direct visualisation using a Judkins Right catheter from the femoral **(A)**. A wire was passed down the left superior vena cava in to the atrium which suggests a left atrial drainage; the wire is visible to the left of the right atrial and ventricle leads **(B)**. With direct venography, it was confirmed that the coronary sinus drains in to the left atrium as seen with flow of dye towards the left in the left anterior oblique **(C)** and posterior-anterior **(D)** views. Chest radiograph demonstrating the final positioning of the leads following an uncomplicated implant **(E)**.
Figure 3: Images of case 3.



The patient was found to have a left superior vena cava (SVC) with no right SVC at a previous procedure in which left subclavian access failed to provide a route to either ventricle. A coronary arteriogram and follow-through identified several large cardiac veins entering the left SVC through a common ostium. A right coronary catheter was advanced into the left SVC from a femoral approach and used to cannulate one of the branches (orange) **(A)**, then changed over a guidewire for a balloon-tip catheter which was used to perform a direct venogram in the favourable vein **(B)**. At a subsequent procedure, the chosen branch vein was cannulated with a delivery system and sub-

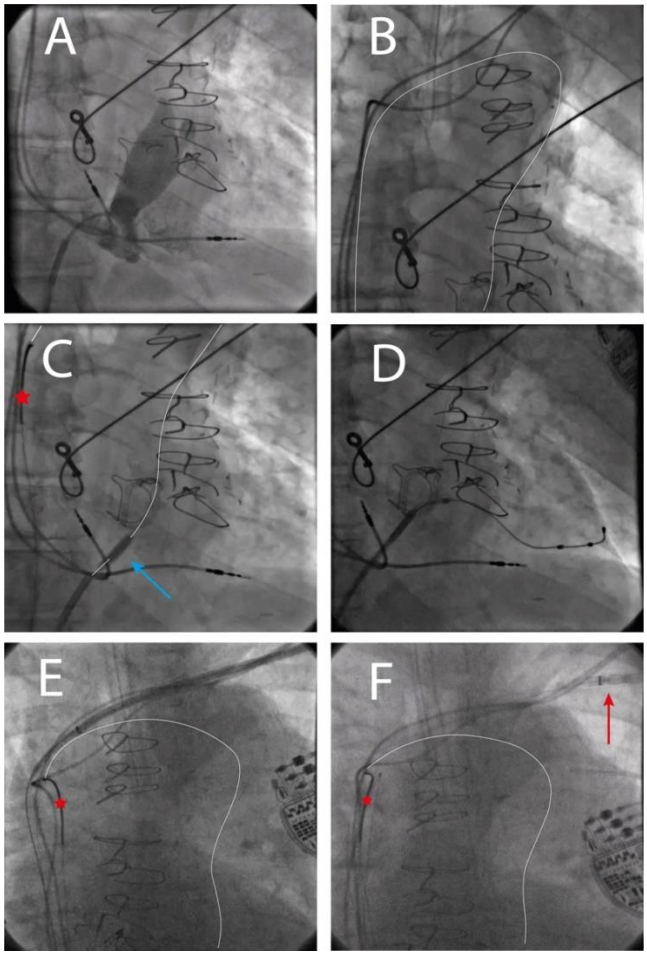
selecting catheter using left cephalic venous access **(C)** to successfully position the left ventricle lead **(D)**. Chest radiograph confirming the final positioning of the leads **(E)**.

Figure 4: Images of case 4



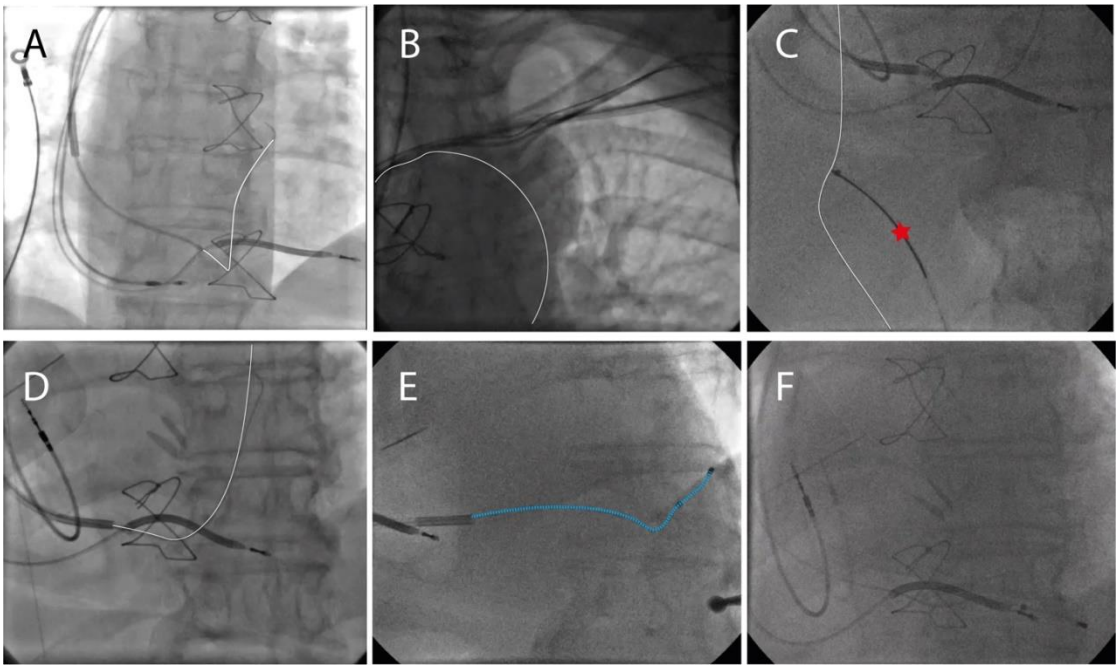
The patient previously had an attempt at CRT-D implantation which failed as the coronary sinus ostium could not be cannulated. Coronary arteriography with follow-through identified several coronary veins which joined to form a coronary sinus which drained to the left subclavian vein **(A)**. Femoral venous access was used to pass a Judkins right coronary catheter over a Terumo guidewire into this vessel to perform a venogram **(B)**. The angulation from the left superior access in to the left superior vena cava was unfavourable and therefore the left ventricle lead was implanted from the right cephalic with smooth access to the coronary venous system **(C-D)**, and then the left ventricle lead was implanted in the high-lateral vein **(E)** with the lead IS-1 connector tunnelled to the generator in left pre-pectoral pocket **(F)** (white line). Chest radiograph demonstrating the final positioning of the leads; the left ventricular lead is implanted via the right cephalic and tunnelled to the left generator pocket (white line) **(G)**.

Figure 5: Images from case 5



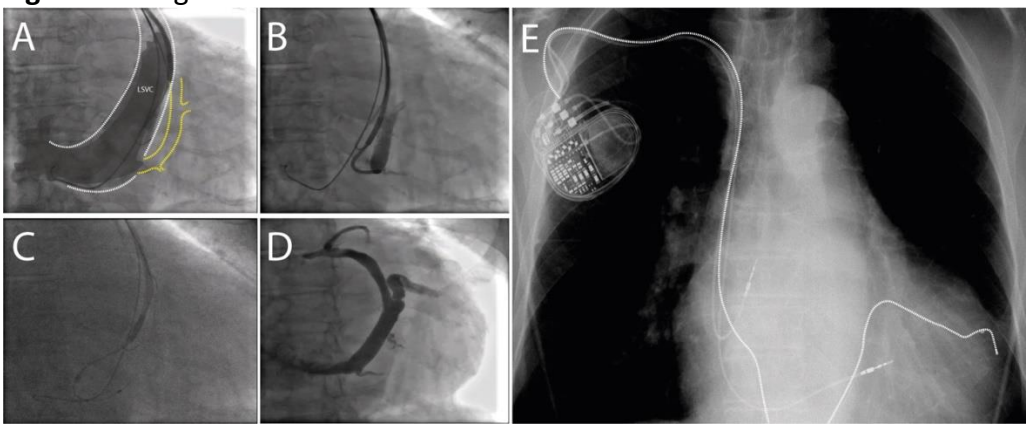
A) The coronary sinus was found to drain via small radical veins to the right atrium and a small persistent left superior vena cava. **B)** An angioplasty guidewire was passed through the radical vein to the coronary sinus and via the left subclavian vein back to the right atrium. **C)** The guidewire was grasped with a Gooseneck snare (red star) via the femoral vein, providing a railroad for a 3.5mm coronary angioplasty balloon to dilate the ostium of the radical vein (blue arrow). **D)** A delivery system was then passed over the guidewire into the coronary sinus and a left ventricular lead delivered to a suitable branch. **E)** A SL0 (St Jude Medical) sheath was passed from the superior access to the femoral access point. **F)** The lead was pulled through from the femoral implant site to a pectoral generator in the standard manner (red arrow).

Figure 6: Images from case 8



A) The guidewire (white line) was introduced in to the coronary sinus with the demonstrable acute angulation. **B)** The 0.014 guidewire (white line) was navigated to the right atrium via the left superior vena cava. **C)** The 0.014 guidewire was snared using a Gooseneck snare from the femoral access to provide a monorail. **D)** A delivery sheath was railroaded over the snared 0.014 guidewire to access the coronary sinus. **E)** The left ventricle lead (blue) was deployed without any difficulty in a suitable lateral vein. **F)** Final fluoroscopy demonstrating all lead positioning.

Figure 7: Images of case 10



The patient was found to have a left superior vena cava (SVC) in addition to the right SVC with no communicating innominate vein. **A)** The coronary venous drainage was into a vein running parallel to the left SVC (yellow line) and joining it near the junction with the right atrium. **B)** Approaching this from the left subclavian vein, there is a sharp angulation entering the coronary sinus to overcome for lead implant. **C)** It proved impossible to get a lead around the sharp bend at the junction of the veins; there was consistent displacement of the lead as attempts were made for implantation. **D)** A right cephalic approach was then used which simplified the angulation to enter the coronary

sinus for left ventricular lead placement; a right-side approach was much more favourable to entering the coronary venous system. **E)** Chest radiograph demonstrating the final position of the right-side implant.

Video 1: Patient 1

Video demonstrating the cardiac resynchronisation therapy implant of patient 1. Levophase venography illustrated that the coronary sinus (CS) ostium arises at the high-lateral right atrium (red circle). The amplatz-left 2 catheter was used to engage the CS ostium and pass the Terumo wire to the distal Left ventricle (LV) vein. A CS delivery sheath was then used to successfully position the LV lead in the postero-lateral branch. (RA = right atrium).

Video 2: Patient 2

Levophase venography was used to depict venous drainage occurring towards the left atrium. A Judkins right catheter was carefully navigated down the left superior vena cava using a 0.014 guidewire (green arrow; white line). A venogram was then performed to directly visualise the cardiac venous drainage, which was occurring into the left atrium (LA), with the coronary sinus ostium clearly sited in the LA (red circle). The left ventricle lead was positioned in the posterior vein (blue line). To mitigate the risk of clot formation and embolization, the patient was prescribed life-long warfarin therapy. (R = right; L = left)

Video 3: Patient 5

Levophase venography was used to visualise the venous drainage of the heart, which illustrated a slow flow via a small vein in to the right atrium (RA). This was confirmed with direct engagement of this small draining radical vein (red circle) using a multipurpose catheter from the femoral access. A 0.014 angioplasty guidewire (white line) was passed through this radical vein to the right atrium via the left superior vena cava (SVC). A 3.5 mm coronary angioplasty balloon was used to dilate the ostium of the radical vein, as the 0.014 guidewire is snared using a gooseneck snare (red star) through the femoral vein; this provided a firm railroad for the 'venoplasty'. A left ventricle (LV) delivery sheath easily accessed the coronary sinus to position a LV lead in a suitable branch. **Femoral pull through:** once the LV lead was successfully sited, axillary access was gained to snare a J-tip guidewire in the SVC which was positioned via the femoral vein (diagonal red arrow). This guidewire was used to railroad a SL0 sheath from the subclavian to the femoral site. Once pulled out of the vasculature at the femoral end, the SL0 introducer and J-tip wire were removed and the LV lead IS-connector was wedged in the mouth of the SL0, which was subsequently tied firmly with silk. The SL0 was then pulled back up to the superior access (green arrow) with the IS-connector firmly held in the mouth of the SL0 (vertical red arrow), to complete the femoral pull through. The LV lead was then connected to the generator at the left superior subcutaneous pocket.