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Transvenous pacing implantation: techniques, tips, and lessons learned along the way☆,☆☆

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Abstract The right ventricular apex has been the traditional site for lead placement in veterinary patients who require permanent cardiac pacing therapy for atrioventricular block and sick sinus syndrome. Implantation of leads in this location is a straightforward procedure that most veterinary cardiologists perform routinely. Pacing at the right ventricular apex, however, has been demonstrated to have long-

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☆☆ A unique aspect of the Journal of Veterinary Cardiology is the emphasis of additional web-based images permitting the detailing of procedures and diagnostics. These images can be viewed (by those readers with subscription access) by going to http://www.sciencedirect.com/science/journal/17602734. The issue to be viewed is clicked and the available PDF and image downloading is available via the Summary Plus link. The supplementary material for a given article appears at the end of the page. Downloading the videos may take several minutes. Readers will require at least Quicktime 7 (available free at http://www.apple.com/quicktime/download/) to enjoy the content. Another means to view the material is to go to http://www.doi.org and enter the doi number unique to this paper which is indicated at the end of the manuscript.

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Right ventricular pacing;
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term deleterious effects on the left ventricular function in numerous patient populations and animal models. Alternative lead placement sites and pacing system configurations have been developed, and the purpose of this review article is not to review the literature or the decision-making process in selecting a specific pacing system but rather to share the experiences of our group with the use of alternative pacing implantation techniques for veterinary patients in need of permanent cardiac pacing.

Abbreviations

LV	left ventricular
PG	pulse generator
PSA	pacing system analyzer
RA	right atrial
RV	right ventricular
RVA	right ventricular apex

Once an indication for pacing has been identified, careful consideration should be given to selecting the most appropriate pacing system for the patient. The most important initial factors that should be considered when choosing the pacing system include the following: (1) bradyarrhythmia diagnosis, (2) patient characteristics (age, size, and concurrent cardiac and systemic disease), (3) available technology, (4) associated costs, and (5) expertise required for implantation of different pacing systems. The traditional method of transvenous implantation of a right ventricular (RV) apical pacing lead programmed to function in a single-chamber, ventricular demand mode is an easy-to-learn procedure with very little alteration in the technique necessary from patient to patient. The placement of transvenous permanent cardiac pacing systems in a single-chamber RV apical pacing location carries a low risk for the major and minor complication rate and is a routine procedure performed by veterinary cardiologists [1—3]. This simple pacing technique, however, has been largely abandoned in pediatric and adult human patients, and the placement of atrial and ventricular pacing leads with sophisticated programming capabilities has now emerged. Veterinary cardiologists are reliant on either previously used and resterilized explanted devices from human patients or purchase of veterinary specific pacemakers[g]

[g] Dextronix, Phoenix, AZ, USA & Infiniti Medical, Redwood City, CA, USA.

There are both theoretical and proven benefits to maintain a physiologic heart rate and ventricular activation sequence during artificial permanent cardiac pacing [4—11]. The purpose of this review article is not to review the literature or the decision-making process in selecting a specific pacing system but rather to share the experiences of our group with adapting newer human adult—manufactured pacing implantation techniques to veterinary patients in need of permanent cardiac pacing.

Lead placement

All patients receiving permanent transvenous pacemaker implantation should be placed in the left lateral recumbency for the right jugular vein access. This way, when placing either RV or right atrial (RA) leads, you are always rotating counterclockwise/toward you and the table/dorsally to manipulate the lead position. When placing a coronary sinus/left ventricular (LV) lead, if the patient is in the right lateral recumbency, the coronary sinus ostium can collapse and close-down, making it difficult to gain entrance. Additionally, the presence of a persistent left cranial vena cava does not affect the implantation technique. The incision and right jugular venotomy should be performed as close to the thoracic inlet as possible to reduce the amount of lead motion that may be created with activity and neck movement.

Atrial-based pacing

Single-chamber atrial-based pacing in small breed dogs with sinus node dysfunction has been evaluated [12,13]. Physiologically, the majority of these patients do not develop clinically significant atrioventricular nodal block and could benefit from promoting atrioventricular nodal conduction with subsequent synchronous ventricular contraction. Transvenous atrial pacing leads are currently manufactured for adult humans. The smallest leads are 4.1—5.1 French and are

recommended for pediatric patients weighing greater than 10 kg [14]. Most veterinary patients with sinus node disfunction are weighing lesser than 10 kg, and as pacing technology evolves, even smaller lead diameters become available; atrial-based pacing using these smaller diameter leads should continue to be evaluated for use in clinical veterinary patients. The authors have used preformed J-shaped leads and straight leads, bipolar and unipolar leads, and active- and passive-fixation leads for atrial pacing. While unipolar leads have only one conductor wire and are thinner than bipolar leads, difficulty with large T waves and noise reversion pacing make these leads less desirable [15]. Use of bipolar straight, active-fixation leads with manually curved stylets into a custom shape are preferred in smaller patients as opposed to preformed J-shaped leads in which the J-shape is too large for small atria and puts too much pressure on the lead tip, which we believe has contributed to erosion through the atrial wall. Thinner and smaller diameter lead tips with a lead tip surface area <2.5 mm^2 are thought to allow for more flexibility and less torque at the lead tip in small breed dogs when single-chamber atrial-based pacing is attempted.

Placement of a pacing lead in the right auricular appendage after jugular venotomy is generally straightforward (see Video 2d). Initially, a straight stylet is advanced together with the pacing lead from the jugular vein and into the RA body. Once the lead tip is seen at the edge of the caudal vena cava (but still within the body of the right atrium), the straight stylet is removed and a preformed J-shaped stylet or a straight stylet customized at the surgical table with a smaller J-shaped curve (preferred in patients smaller than 5 kg to prevent the lead from advancing past the tricuspid valve) is placed to direct the lead tip toward the right auricular appendage. The ideal location for the atrial lead is somewhat high in the RA appendage. The lead and stylet may need additional dorsal rotation and/or gentle pushing of the lead to allow it to hook into the appendage. Once it is in a desired location, withdrawing the lead and stylet back slightly may allow for the tip to have good apposition to the atrial myocardium. For active-fixation leads, clockwise rotation at the terminal pin of the lead causes the helix to advance into the atrial myocardium. The number of rotations required should actually be assessed before placing the lead within the jugular vein. Once the lead is thought to be in a good position, the J-shaped stylet is removed and a windshield wiping motion of the lead tip to the ring length should be visualized during atrial contraction. To ensure an auricular lead is well attached to the atrial myocardium, the lead (without stylet in place) location and position do not change while the lead is advanced slightly. Enough slack should be left within the lead body to allow for side-to-side neck motion of the patient. An excessive amount of slack should not be advanced into the RA body as this could allow for the lead to be displaced across the tricuspid valve and the lead tip to be dislodged (Fig. 1A and B).

Another approach to atrial-based pacing in small breed dogs is implantation of a non-retractable active-fixation helix tip pacing lead in the interatrial septum (see Fig. 2). There are both theoretical and proven physiologic reasons [16] and procedural considerations [12] for alternate atrial pacing locations for small breed dogs. Pacing of the atrial septum has been shown to significantly reduce interatrial conduction time and reduced P wave duration, leading to more

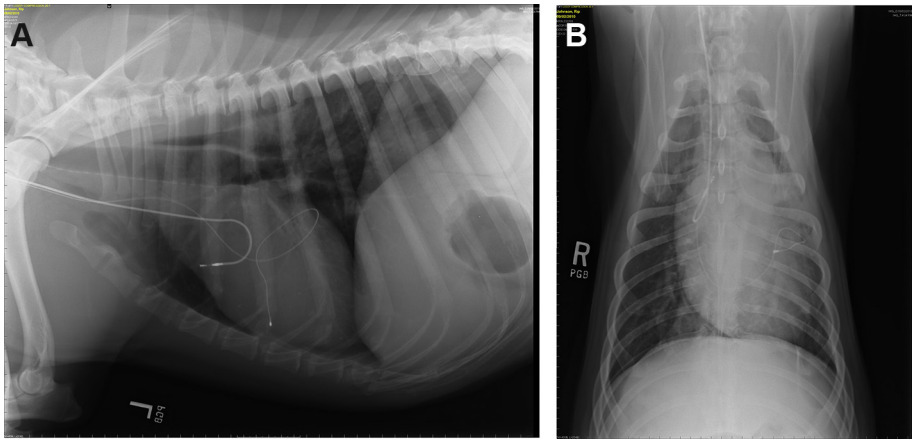

Figure 1 Left lateral (A) and ventrodorsal (B) radiographic views of a dog with a right atrial lead and a left ventricular free wall lead. The tip of the right atrial lead is positioned in the right auricle.

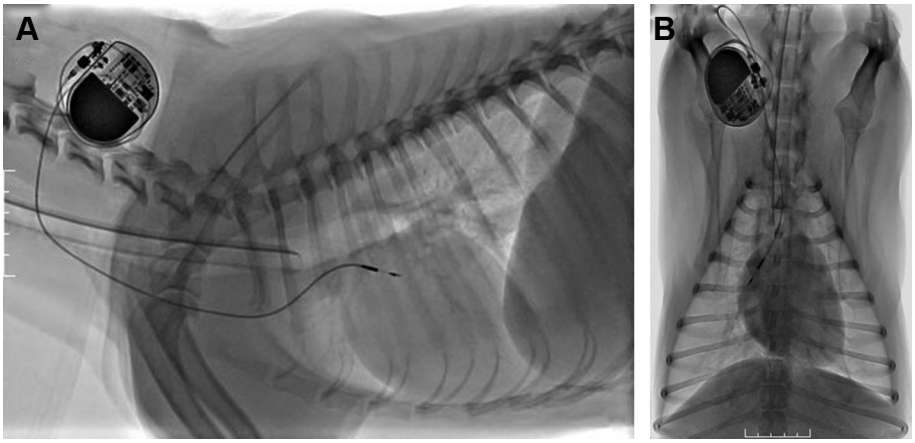

Figure 2 Left lateral (A) and ventrodorsal (B) radiographic views of a dog with a right atrial lead fixed in the atrial septum.

synchronous atrial contraction [17,18]. A modified LV 90° angle tipped delivery catheter[h] and a 4.1-French bipolar lead[i] are advanced together through the jugular venotomy toward the left side of the dog until resistance is felt, and a slight bending of the tip of the guiding catheter against the septum is seen on fluoroscopy [19]. Owing to the presence of a permanently exteriorized screw at the tip of this catheter, once the delivery system is in an appropriate location, the pacing lead is then advanced slightly outside the distal end of the guiding catheter and the entire lead is rotated approximately 4—5 times to achieve fixation. The guiding catheter is then backed away to expose the lead anode. (Videos 1a—c) A pacing system analyzer (PSA) is then used (as described in the following section) to determine the lead position and stability and gentle traction is applied to the lead to ensure adequate fixation. The delivery catheter is then cut away from the lead using an adjustable slitter[j] (see Video 3).

Ventricular-based pacing

Placement of a pacing lead within the RV apex (RVA) is generally very straightforward and is currently the most common location for permanent artificial cardiac pacing in veterinary patients. Pacing leads are typically packaged together with multiple stylets including curved and straight tips. The authors use only the straight stylet when implanting RV apical leads but prefer the 14-gauge guidewire as this is more flexible at the tapered end. The straight stylets also contain a ball at the tip, which allows for improved locking into the lead, which the authors feel would allow for more control for lead guidance. After the pacing lead and straight stylet are passed into the jugular venotomy and the tip of the lead is within the right atrium, a curve in another straight stylet is customized at the surgical table with the fingers or a hemostat based on the patient size. The straight stylet is then replaced with the custom-curved stylet to help cross the tricuspid valve. The curved stylet is then removed and exchanged for a straight stylet to guide the lead to the RVA. Orthogonal fluoroscopic or radiographic (left lateral and dorsoventral views preferred) views can be helpful to confirm the placement of the lead tip in the RVA; the lead is appropriately at the RVA when the tip is seen to be at the caudoventral aspect of the cardiac silhouette on a lateral view (Fig. 3A) and deviates slightly toward the midline on the ventrodorsal projection (Fig. 3B). For an active-fixation lead with an extendable and retractable helix, the lead is gently pushed against the RVA endocardium and rotated clockwise with a torque device placed at the distal pin of the pacing lead. The authors will often zoom the fluoroscopy unit onto the area of lead implantation such that full extension of the helix can be visualized. The authors also assess the number of rotations necessary to extrude the helix before placing the lead within the jugular vein. There are also open helix lead types including a mannitol capsule, which dissolves within approximately 5 min of being in the blood pool. The authors do not prefer this lead because of the timing needed and concern for readjustment of the position with an open helix

[h] Attain Select® II standard 90 Left Heart delivery catheter, Medtronic Inc, Minneapolis, MN, USA.
[i] SelectSecure Model 3830 Lead, Medtronic Inc, Minneapolis, MN, USA. Attain Select II Left Heart Lead Delivery System 6248V-90P, Medtronic, Inc, Minneapolis, MN, USA.
[j] Adjustable slitter, Medtronic Inc, Minneapolis, MN, USA.

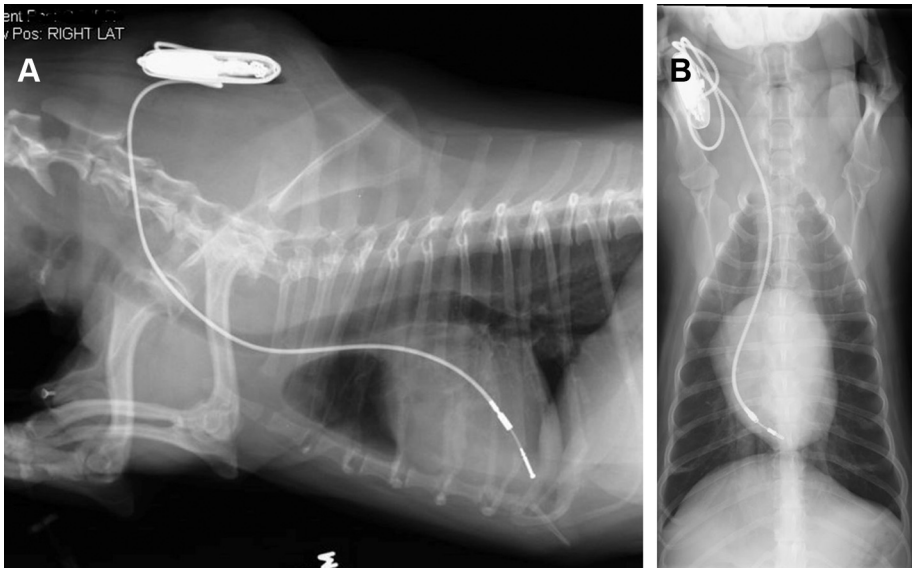

Figure 3 Right lateral (A) and ventrodorsal (B) radiographic views of a dog with a VVI pacemaker and the tip of the active-fixation lead positioned in the right ventricular apex. VVI, ventricular demand pacing.

and possibly entangling within trabeculation or rarely the tricuspid valve. With passive-fixation leads, the placement of the lead is identical except there is no need for use of a torque device and instead the lead and straight stylet are positioned as deep into the RVA as possible. The lead tip is watched as mentioned previously for any motion that may occur with removal of the stylet. To assure that the lead is in a good position, the lead is advanced and again watched to ensure that there is no movement of the tip. A PSA is also used at this point and described in the following section for each lead type to ensure adequate placement.

Dual chamber systems with a single lead that allows for atrial synchronous ventricular-inhibited pacing use one pacing lead that incorporates both a pacing electrode within the right ventricle and a floating atrial electrode within the intra-atrial portion of the ventricular lead to sense P waves propagated through the blood (Fig. 4). These native P waves are sensed by the pacemaker, and then after an appropriately programmed atrioventricular delay, the system delivers a ventricular pacing impulse. The atrial synchronous ventricular-inhibited pacing lead is advanced through the jugular venotomy site and implanted within the RVA as described previously. The set distance between the floating atrial electrode and ventricular pacing tip (11.5—14 cm) often prevents its use in small dogs. When using these leads, the floating atrial electrode needs to be positioned close enough to the cranial vena cava to properly sense native P waves. In some smaller dogs, the 11.5-cm space atrial synchronous ventricular-inhibited pacing lead can still be used with an 'S'-shaped configuration [20] (Fig. 4). In our experience, the use of an excessive amount of lead slack with any lead increases the risk for dislodgement as the loop can prolapse across the tricuspid valve and into the RV outflow tract.

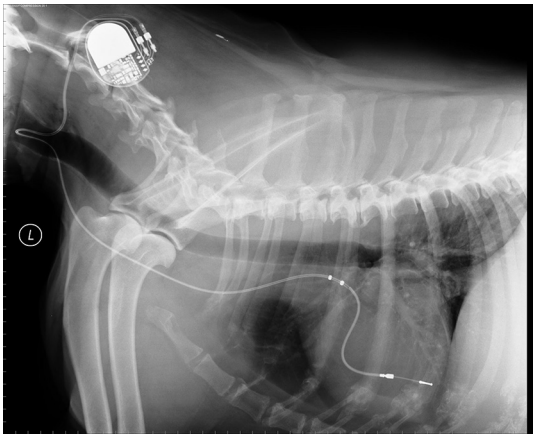

Figure 4 Right lateral radiographic view of a single VDD lead in a small dog demonstrating the formation of an 'S'-shape to advance the floating atrial electrode near the cranial right atrium and sense P waves adequately. VDD, atrial synchronous, ventricular-inhibited pacing.

In the last decade, there has been a surge of interest in the human adult and pediatric pacing arena regarding the sequence of ventricular activation and the search for more optimal ventricular pacing sites. Therefore, alternative RV pacing sites have been proposed, including septal, para-Hisian, and outflow tract sites. True RV outflow tract

pacing is right under the pulmonary valve where the endocardial surface is very smooth, making it difficult to implant a lead that will not dislodge. Additionally, this type of pacing has been shown to promote dyssynchrony and possibly produce a pacemaker-mediated cardiomyopathy.

Our group has used RV septal pacing because there is more tissue to engage and implant within [21]. The RV funnels down to a groove, which allows veterinary cardiologists to use septal/RV groove pacing in an attempt to allow for improved synchronization to ventricular contraction. For this location, an active-fixation lead is necessary. While there are trabeculations in this region, they are not as extensive as the RVA and a passive-fixation lead would not be as stable. A standard active-fixation lead with an extendable helix is used similar to RVA pacing leads. The stylet is customized at the surgical table to have a smaller curve at the end such that the guidewire and lead can be rotated together in a clockwise manner this time, directing the lead tip toward the septum/RV groove and not toward the free wall. Biplane fluoroscopy is ideal for placing a lead in this location. Once the lead and customized stylet is past the tricuspid valve, another customized guidewire with an even smaller curve at the end may need to be exchanged within the lead to allow for rotation of the lead clockwise/away from you and the table and for the lead to engage the ventricular septum/RV groove. Once there, you will not be able to direct the tip either toward the free wall or septum because it has really just settled into the RV groove. In the past, the 'prolapse' technique was used where a pacing lead without a center stylet was curled into the RA and then dropped into the RV. With that technique, after the lead was dropped into the RV, a straight or customized stylet was then placed through the pacing lead to manipulate the lead position within the RV. We have found this to be less ideal because the lead will tend to track and get stuck behind the chordae tendinae, thus impairing the ability to maneuver and guide the lead into the RV groove. The surgeon will need to adjust the slack on the lead by advancing and retracting the lead while assessing the feedback on the lead. When there is too much slack, there will be a lot of septal 'dancing' of the lead and often associated with increased RV ectopy. When there is too little slack, the tip of the lead will change in direction. Once the RV lead is placed, neck motion and how motion may affect the position of the lead are simulated by pulling the proximal ligature cranially. Once the lead is confirmed to be in an optimal position, the PSA is attached to do threshold testing, impedance, and standard lead stability assessments. Use of a rotational fluoroscopic or at least biplane unit is absolutely necessary to visualize the correct orientation toward the septum versus the free wall of the RV (Fig. 5).

The LV pacing systems are typically not used independently and are manufactured as part of a cardiac resynchronization therapy where there are leads placed in the right atrium, right ventricle, and cardiac vein (typically the left marginal vein or left posterior vein) that overlies that LV free wall (LVF). There are different types of LV leads with different patented styles of passive-fixation techniques. The coronary venous anatomy in a dog is similar to that of humans and, similarly, it is not uncommon to encounter coronary venous anatomy over the left free wall with acute angles, anastomoses, or multiple small draining vessels which

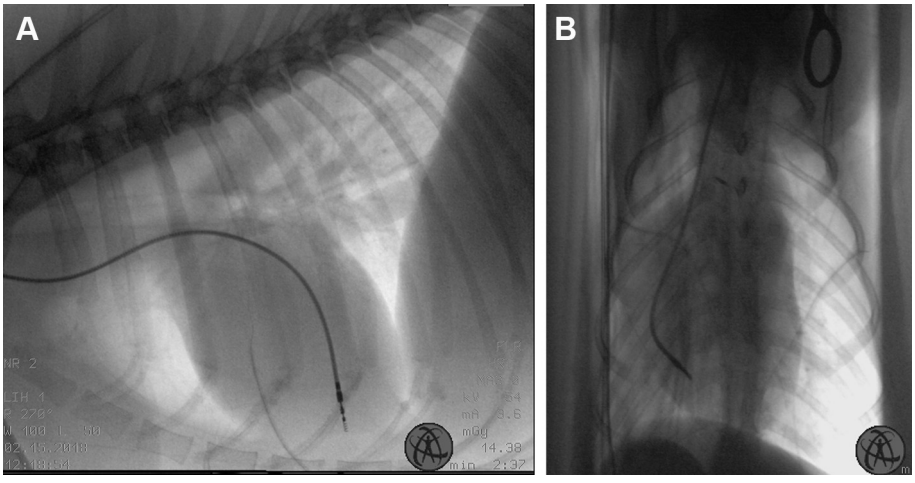

Figure 5 Right lateral (A) and dorsoventral (B) radiographic views of a dog demonstrating appropriate placement of a right ventricular septal lead.

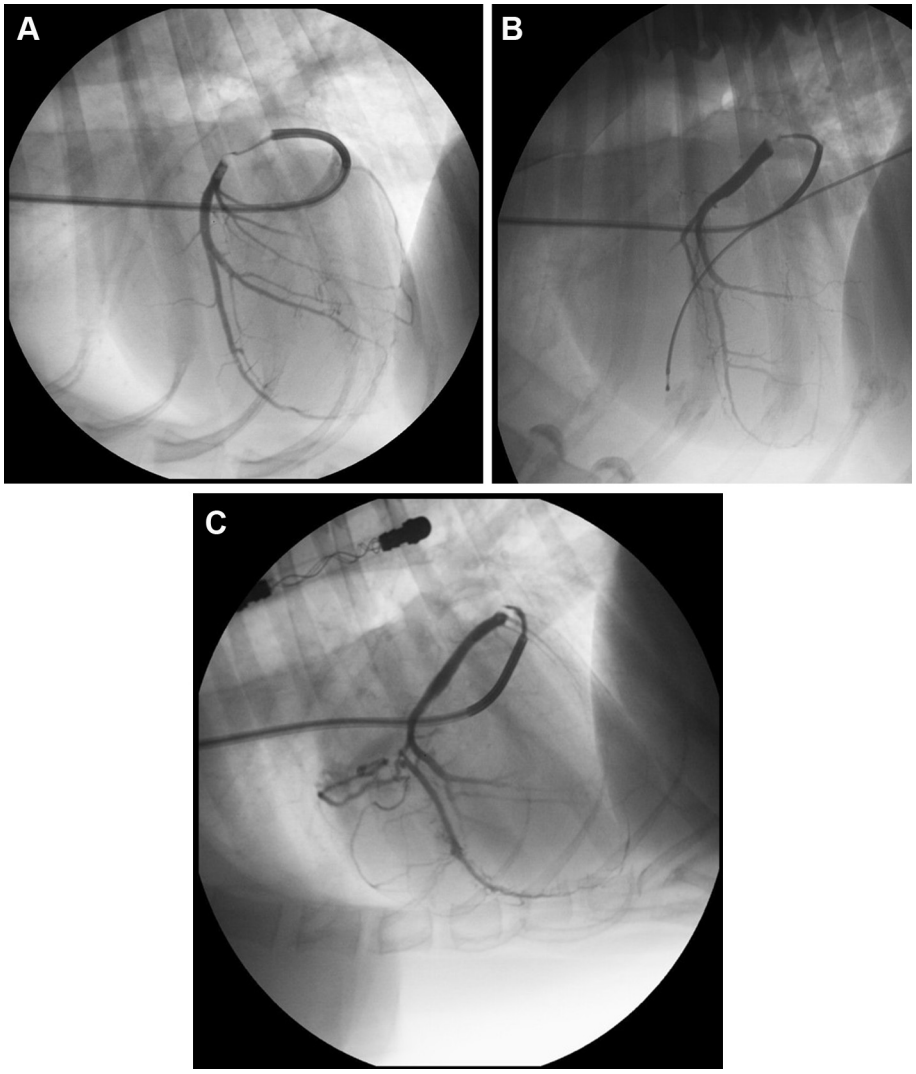

Figure 6 Lateral fluoroscopic images with retrograde coronary venography via the coronary sinus. These demonstrate a great cardiac vein of adequate diameter and anatomy for the placement of a left ventricular free wall (LVF) lead (A), multiple branches and bends of the coronary veins (B), and coronary veins with acute angles and partial anomalous drainage directly to the right atrium (C). An LVF lead could not be placed in either of the latter (B and C).

make the placement of an LV lead difficult or impossible (Fig. 6 and Videos 2a—d). There are several techniques and systems available for the placement of LV pacing leads, following the access to the coronary sinus. The following is the system we have used at the University of Florida using a steerable electrophysiology catheter.[k] This catheter is used to position a guiding catheter[l] into the coronary sinus. Next, a retrograde venogram is performed through the guide catheter with a balloon-tipped end-hole catheter[m] to obtain a map of the coronary venous system and select the appropriate coronary vein for lead placement. Once an appropriate coronary vein is selected, the balloon-tipped catheter is removed. This 'road-map' image should be saved and displayed next to or overlaid on top of the live image. A unipolar or bipolar over-the-wire LVF lead[n,o] is then placed in the selected coronary vein through the LV guide

[k] RF Marinr SCXL steerable electrophysiology catheter (5 Fr), Medtronic, Inc, Minneapolis, MN.

[l] Attain guide catheter (9 Fr) model 6218, Medtronic, Inc, Minneapolis, MN.

[m] Attain venogram balloon catheter (6 Fr) model 6215, Medtronic, Inc, Minneapolis, MN.

[n] Attain OTW unipolar pacing lead (4 Fr) model 4193, Medtronic, Inc, Minneapolis, MN.

[o] Attain OTW bipolar pacing lead (6 Fr) model 4194, Medtronic, Inc, Minneapolis, MN.

catheter with the use of a 180 cm 0.014 in guidewire. Putting a small bend on the tip of the 0.14 guidewire may be useful to allow guidance down the selected lateral cardiac vein. Sometimes, the provided stylet may be useful instead of the guidewire to straighten or place a particular bend in the lead to traverse difficult venous anatomy. The lead must be fed as deep as possible into the lateral vein for stability (Fig. 1A and B). Some newer LV leads are quadripolar to allow numerous pacing configurations to optimize the pacing site without sacrificing the lead stability. Ensure that there is a 'natural' bend to the LV catheter and it is not straight. Veins without a gentle bend have an increased risk of dislodgment. Before the lead assessment testing, the guidewire must be retracted into the lead to prevent the guidewire from serving as an electrode. However, the guidewire should be left within the body of the lead until all implants are placed so that if the LV lead dislodges during procedure, it can be easily replaced.

The guide catheter is then simultaneously removed and cut from the LVF lead with the supplied slitter/cutting device. First, the slitter is gently worked through the harder plastic introducer end of the guide catheter being sure to begin at the groove. Then, when using the slitter/cutting device for LV leads or 3830s, the hand that holds the slitter (usually the right hand) is completely frozen on the animal and physically sits on the neck holding both the slitter and the lead totally still. The other hand (usually the left) pulls the guiding catheter very steadily and slowly to cut it off while leaving the lead in place.

The use of multiple pacing leads in different combinations of the previously mentioned implantation techniques has been shown to be possible, associated with increased implantation time, but without increased risk of either minor or major complication rate [22]. When implanting multiple leads, in our group, the first step is always to write down the serial numbers of the leads to avoid complication or confusion as to which lead should be connected to which generator pacing port. When using biventricular pacing systems, we always place the LVF lead first and the RV lead second. The last lead we always place, even if using only RA/RV pacing systems, is the atrial lead.

PSAs/lead testing

Before securing the leads or plugging them into the pulse generator (PG), multiple parameters of lead site integrity and suitability should be tested using a PSA. These parameters include sensed P wave amplitude (if implanting an RA lead), sensed R wave amplitude (for ventricular leads), current of injury, lead impedance, and threshold testing. When using a PSA during implantation, sterile patient cables are connected to the pacing leads with the red lead on the ring of the pacing lead and the black lead on the tip (if using a bipolar lead) or on the skin edge of the incision (if using a unipolar lead). For quick reference, the authors typically remember this as 'red ring, black back'.

When placing an atrial lead, regardless of where the RA lead is placed, the PSA is used to assess lead impedance and sensed P wave amplitude. An adequately placed RA should sense P waves that are anywhere from 2 to 10 mV in healthy atrial myocardium. If it is less than 2 mV, it is not an adequate location for implantation and the lead should be repositioned. In our experience, most leads within the right auricular appendage or RA septum sense P waves that are between 3 and 3.5 mV. Another important point when assessing P wave amplitude is to make sure to adjust the sensitivity so that you are actually sensing P waves and not getting false readings from far field sensing of R or T waves which would make interpretation of P wave amplitude artificially high. With a ventricular lead, the R wave amplitude is measured to ensure that the pacing lead can 'see' complexes well enough. Generally, an appropriately placed RVA pacing lead will measure/sense an R wave that is at least 10 mV (and usually higher). With RV septal/groove placement of leads, the R wave amplitude will be much smaller than that with RVA leads. Acceptable R wave amplitude in these locations is 4—5 mV because of the perpendicular alignment of the dipoles and also because there is less muscle and vector in this plane. LV leads will generally sense larger amplitude R waves than RVA leads. In our population of dogs with implanted LV leads that were stable long term, we have seen R wave amplitudes of 15—20 mV [23,24], which are similar to LV leads implanted in human patients for resynchronization therapy [25,26].

Both passive- and active-fixation leads are initially traumatic to the myocardium when implanted and can temporarily cause increased pacing threshold. The magnitude of this current of injury can be assessed with a PSA and is characterized as prolongation of the atrial or ventricular depolarization and ST segment elevation on the intracardiac electrogram [27] (Fig. 7). While the veterinary authors of this article do not routinely use the current of injury as a marker for lead stability, we do typically wait 5—10 min after

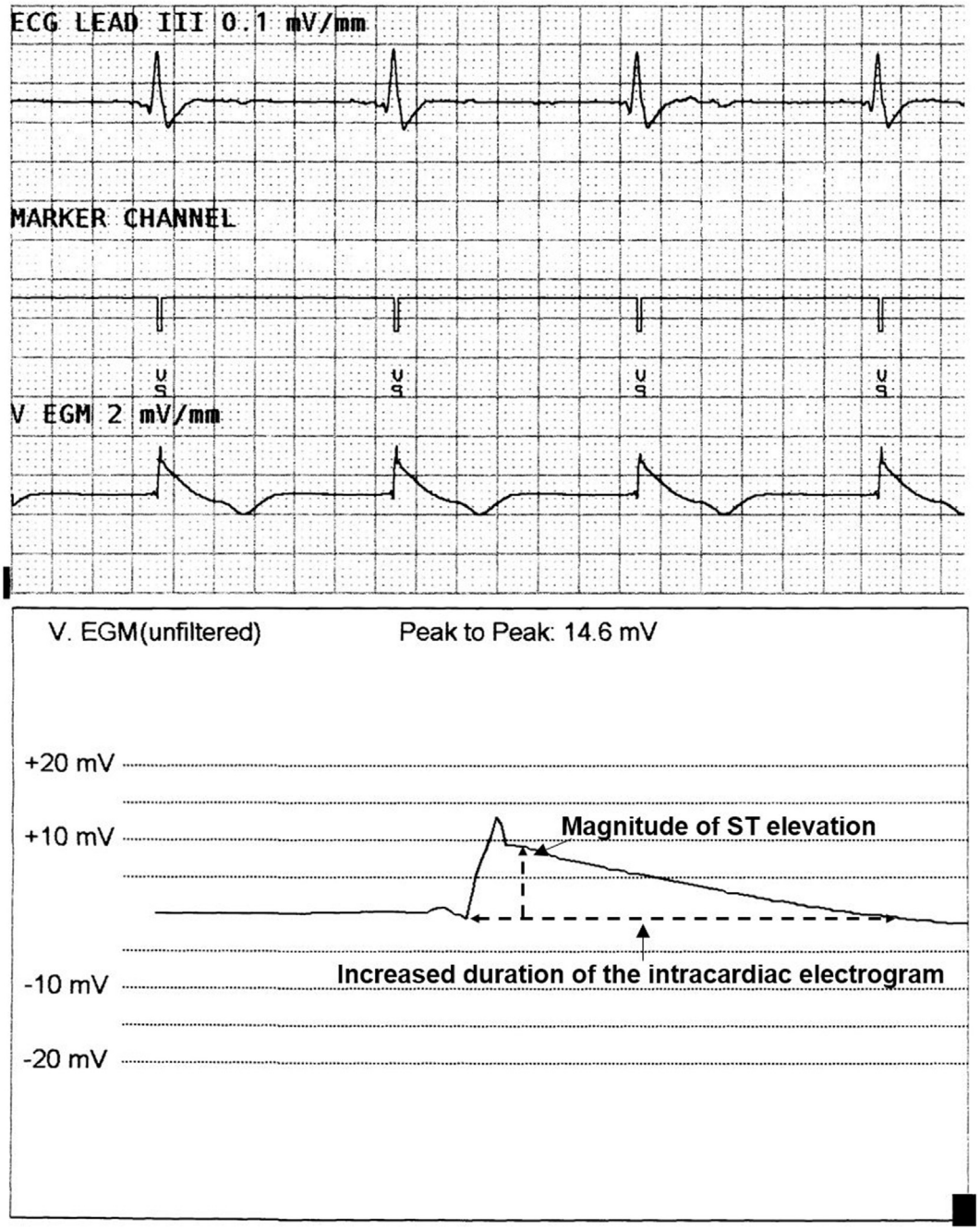

Figure 7 The current of injury indicated by an increase in the duration of the intracardiac electrogram (msec) and the magnitude of ST segment elevation (mV) can be used to assess the adequacy of active-fixation at the time of lead implantation.

placement of an active-fixation lead before performing threshold testing to allow the acute injury to the myocardium to decrease and give more reliable threshold testing information. Recommendations and current practice for pediatric and adult pacemaker patients is that presence of an adequate current of injury should be used routinely as it correlates well with adequate lead fixation and long-term lead stability of active-fixation atrial and ventricular pacing leads [25,27,28].

Next, the impedance of the placed lead is determined. Impedance is the total resistance to current flow and gives information regarding the integrity of the pacing system. For both the right auricular appendage and RVA as well as RV septal leads, impedance should generally be between 500 and 1000 Ω at the time of implantation. Atrial

septal pacing leads should have an impedance of 900—1200 Ω. Impedance is much higher with LV leads that are placed from the coronary sinus because these are located within the blood pool and not in direct contact with myocardium. The impedance for these leads can be as high as 3000—4000 Ω.

Finally, and most importantly, the threshold for pacing is determined. The threshold for cardiac pacing is the minimal electric stimulus required to cause cardiac muscle contraction. This is typically performed in a step-down fashion where first, the pulse voltage is dropped while keeping the pulse width constant, and next, the pulse width is decreased while keeping the voltage constant to find the threshold for minimal pacing to occur. The authors consider a lead in a good position and will leave a lead in place when acute pacing threshold is at or below a pulse amplitude of 1.0 V and a pulse width of 0.5 ms (for example if pacing is not lost until a pulse amplitude of 1.0 V or 0.4 ms). Typically, the acute pacing thresholds drop all the way down to the lowest possible voltage and pulse width before losing capture in most implanted leads. For safety reasons and because of the acute inflammation that likely occurs after implantation, a margin of two to three times the pacing threshold is initially programmed to ensure that capture/contraction will occur. Threshold testing is typically performed again the following day, at 2—3 weeks (can be scheduled at suture removal time point), and at 3 months. At 3 months, unless there have been changes in thresholds, the pacing system and lead tip is considered stable enough where pacing thresholds will have typically decreased the pulse voltage, and pulse width can be reduced to maximize battery life and pacemaker function.

Alternatively, in many devices, the pacing system is capable of being programmed for 'capture management'. Threshold values can change on a day-to-day basis. Thus, when programming voltage output, it is advisable to use a two to three times safety margin above the threshold value. This 'extra energy' is a drain on the battery and helps to speed depletion and need for replacement of the PG, but is unfortunately necessary. Capture management is a feature that was designed to ensure reliable capture on a beat-to-beat basis without the need for a large safety margin. With this feature turned on, the pacemaker will assess the threshold on every beat and adjust pacing output values accordingly. If an output does not capture the heart, a back-up pulse (which is larger in output) is delivered. Over the long term, this algorithm allows for far less energy use and longer functioning of the generator before replacement is required.

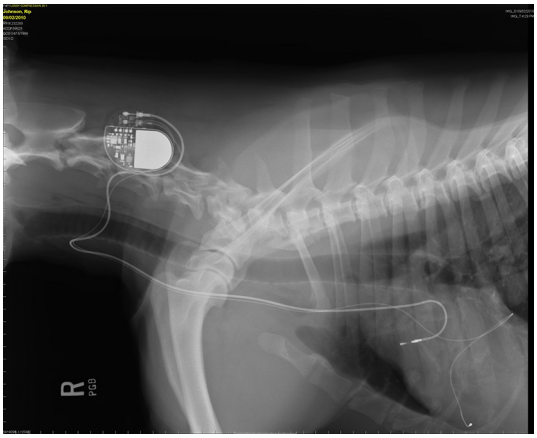

Figure 8 Right lateral radiographic view of a dog with a right atrial lead and a left ventricular free wall lead demonstrating an adequate but not excessive amount of lead slack for each pacing lead. In the cervical region, the leads are tacked to the underlying tissue in an 'S'-curve to allow neck motion.

Initial securing of the leads

For isolation and manipulation of the jugular vein and fixation of the lead in the vein, our group uses 2-0 silicone-coated braided polyester (2-0 Ti-Cron),[P] not nylon or silk, because it can be tied very tightly without damaging the lead and maintains its tensile strength permanently.

We use the anchoring sleeve only for larger jugular veins when it fits easily into the lumen and only when pacing a single lead pacing system. Otherwise the anchoring sleeve is cut away using small iris scissors or the anchoring sleeve is used to tack the lead into a stable long-term position as described in more detail in the following section. We place our first ligature around the lead(s) encircling the jugular vein before inserting the anchoring sleeve into the jugular vein. After the first ligature is placed around the lead(s), and before securing the remainder of the ligatures around the leads, one can simulate neck and head turning by pulling on the ligated suture around the jugular vein and lead(s). This is performed while watching the lead body(ies) and lead tip(s) to ensure that they do not move from the position that you intended them to be in. It is also important to watch along the length of the leads during this motion to ensure there is appropriate slack within each lead (Fig. 8). The second ligature should go around the lead and anchoring sleeve within the jugular vein and tied tight. The third ligature should go at the top of the anchoring

[P] Ti-Cron suture, Covidien, Dublin, Ireland.

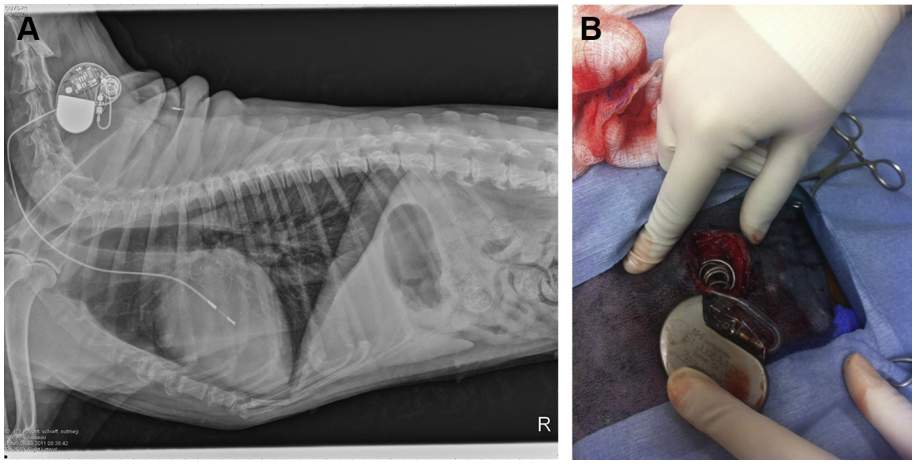

Figure 9 Right lateral radiographic view of a dog with twiddler's syndrome (A). Note that the lead is coiled in the generator pocket because of the pulse generator repeatedly rotating within the pocket. This has caused the tip of the right ventricular lead to dislodge from the apex. The coiled lead is observed in the generator pocket at the time of surgery to replace the lead (B).

sleeve (if it is used) such that it is exerting mild gentle additional pressure to push it into the lead.

When using multiple leads, the anchoring sleeves are usually moved proximally and used to individually tie each lead into the two grooves of the anchoring sleeve in an 'S'-curve above the jugular venotomy incision (Fig. 8) (described in more detail in the following section when discussing generator fixation). Before securing lead(s) in place outside of the jugular vein, it is important to first ensure there is appropriate slack within each lead. Neck motion is again simulated to ensure the lead tip(s) do not move.

Generator fixation

There are multiple ways that have been described and taught for where and how to implant the PG. Some institutions create a subcutaneous pocket using manual dissection just dorsal to the incision made for the jugular venotomy with the size of the pocket determined by attaching and looping leads underneath the PG. This pocket is made larger if necessary to allow leads and generator to sit within the pocket without any tight bends or acute angles seen on fluoroscopic evaluation. Other institutions use a second incision in the mid to upper third of the thorax caudal to the shoulder and tunnel the leads subcutaneously to connect to the PG. Regardless of where the PG is placed, it is important that the pocket is small to reduce the chance of rotation of the PG and development of twiddler's syndrome (Fig. 9). The authors of this article prefer to make a second incision dorsal to the jugular venotomy incision and use blunt dissection under this incision to make a small pocket just below a thin subcutaneous muscle of the neck, the platysma. The pocket is intentionally made to be small in size where the PG is placed somewhat snugly. Using hemostats, leads are then tunneled from the jugular venotomy site and up into the second incision, and leads are connected to the PG with a wrench in a clockwise rotation. The wrench creates a clicking sound when in place, and only one click should be made. Continuing to rotate the wrench and set screws could result in malfunction of the pacing system. If there are any ports not used (i.e. if only one lead is placed but a dual chamber PG is the only one available), a port plug should be placed. The remaining loops of the pacing lead are placed below the PG and then placed together within the pocket. Fluoroscopic evaluation of the PG and leads is again performed to ensure there are no tight bends or acute angles created when the PG and leads are placed within this pocket. Once the surgeon is satisfied with the PG pocket, the entire pacing system is taken out, a single suture (the authors use 2-0 Prolene[q]) placed deep within the pocket preferably within and below the thin muscle layer and then looped into the suture hole on the head of the PG. The entire pacing system is then replaced back into the pocket and the suture is tied. Fluoroscopic evaluation of the PG, lead loops, and lead slack are made one final time before the incision sites are closed. The neck is wrapped with a sterile bandage, and lateral and dorsoventral (DV) radiographs are taken before the patient is awakened and recovered quietly.

[q] Prolene suture, Ethicon US, Somerville, NJ, USA.

Patients are given standard intra-operative antibiotics (cefazolin 22 mg/kg[r] at anesthetic induction and every 90 min thereafter) and also sent home with a 2-week course of antibiotics (cephalexin 22 mg/kg BID[s]). Other methods of prophylactically attempting to reduce the risk for implant infection such as use of an antibacterial envelope,[t] or placement of injectable antibiotics into the pocket of the generator, have not been used by the authors of this review article. It is the authors' opinion that the risk for infection of an implanted device in an individual patient should be weighed on a case-by-case basis. Risk factors known to contribute to this risk would include the underlying systemic diseases, urinary tract infections, skin infections, lack of prophylactic antibiotics, and use of a temporary pacemaker [29—38]. The authors' do recommend an extensive medical workup before device implantation to assess the risk for device implant infection ahead of time and delay if possible by 1—2 days the procedure if possible to allow for either oral or intravenous antibiotic therapy.

Conflict of Interest Statement

The authors do not have any conflicts of interest to disclose.

Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jvc.2018.08.002.

Video Table

Video Number	Title	Description
1a	Interatrial Septal Pacing — Advancing modified LV catheter	Advancement of modified LV catheter toward the interatrial septum, with slight bend in tip of the catheter indicating the location of the interatrial septum.
1b	Interatrial Septal Pacing — Placement of atrial lead	Gentle pressure is applied via the guiding catheter as the tip of the pacing lead is manually extruded and rotated to fix the screw in the interatrial septum. The guiding catheter is then backed away, leaving the lead fixed in position.
1c	Interatrial Septal Pacing — Atrial lead rotational	90 degree rotational image showing the proper position for interatrial septum pacemaker lead.
2a	Placement of LV pacing system — Retrograde venogram pt. 1	Retrograde venogram performed using a balloon tipped catheter placed in the coronary sinus via a guiding cathether. This patient has excellent coronary venous anatomy for placement of an LV pacing lead. A temporary pacemaker lead is also positioned in the right ventricle via the saphenous vein.
2b	Placement of LV pacing system — Retrograde venogram pt. 2	Retrograde venogram in a second patient showing poor coronary venous anatomy for placement of an LV lead. Note the narrow vessels and acute angles.
2c	Placement of LV pacing system — Fluoroscopy LV pacemaker lead	Fluoroscopy image of adequately placed LV pacemaker lead via the coronary sinus. A temporary pacemaker lead is also positioned in the right ventricle via the saphenous vein
2d	Placement of LV pacing system — Fluoroscopy J-tip pacing lead	Fluoroscopy of the same patient showing the LV pacemaker lead as well as the temporary pacemaker lead in the RV. As the final step, a J-tip pacing lead was positioned in the right auricular appendage.
3	Placement of LV pacing system — Adjustable slitter	Example of using adjustable slitter for removal of guiding catheter. Note that the hand holding the slitter does not move while the opposite hand gently pulls the guiding catheter through the slitter. The tip of the lead would be fixed in the myocardium, thus avoiding the significant movement noted in this sample video.

[r] Cefazolin USP, Sandoz, Broomfield, CO.
[s] Cephalexin, Ivax Pharmaceuticals, Miami, FL.
[t] AIGISRx antibacterial envelope, Tyrx Inc., Monmouth Junction, NJ.

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