

ProPlege Peripheral Retrograde Cardioplegia Device™ Placement

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Introduction

Minimally invasive cardiac surgery utilizes a variety of specialized devices and cannulae. The coronary sinus (CS) device has gained a reputation for being the most challenging of these devices to place. Several imaging strategies have been described for guiding device placement. Transesophageal echocardiography¹ (TEE) and fluoroscopy² have been used alone for guidance. Combined use of TEE and fluoroscopy has also been common since the inception of port access cardiac surgery.^{3,4,5}

The first challenge in placing a ProPlege Peripheral Retrograde Cardioplegia Device™ is engaging the coronary sinus ostium. The ostium is the smallest of three potential targets, being half the diameter of the inferior vena cava (IVC) and one-quarter to one-third the diameter of the tricuspid inlet. Engagement requires active manipulation. The second challenge is advancing the ProPlege device beyond the CS ostium. The device can enter side branches or be impeded by obstructions. Advancement into the distal CS is not guaranteed.

Various skills aid the learning process. Some knowledge of TEE is needed, although expertise is not essential. Non-standard TEE views can make the difference between easy and difficult placement. Applicable fluoroscopy builds on familiar landmarks seen in a PA chest x-ray. Knowledge of the anatomy of the coronary sinus and surrounding structures allows logical device manipulation and the best use of imaging and monitors.

General overview

This article describes the author's approach to placing and troubleshooting a ProPlege Peripheral Retrograde Cardioplegia Device™. The technique adopted by each individual will be influenced by medical judgment and institutional circumstances. It is essential that the practitioner read and follow the manufacturer's Instructions for Use (IFU) prior to use. Although this article strives to be complete, it is not the final word on cannulation technique, applied imaging, or coronary sinus anatomy. An Appendix contains supplemental information on coronary sinus anatomy, TEE imaging, fluoroscopy, and other aspects of CS device placement.

Descriptions of TEE adjustments are as follows:

The probe is advanced or withdrawn in the esophagus
The multiplane angle is increased or decreased
The probe is turned right (clockwise) or left (counterclockwise)

Descriptions of anatomic direction are made with respect to the heart:

The head is superior; the feet are inferior
The sternum is anterior; the spine is posterior
Right and left are as expected

Descriptions of the TEE display place the sector apex at the top of the screen, with the right half of the sector displaying left structures at a multiplane angle of 0° and superior structures at a multiplane angle of 90°. Discussion of TEE is limited to 2D imaging.

ProPlege device placement can be divided into three sections: pre-insertion preparation, device engagement of the CS ostium, and device advancement beyond the ostium. Imaging, technique, and troubleshooting are reviewed for each section.

ProPlege device placement method

Pre-insertion Preparation

- Perform initial device preparation (e.g. back table)
- Perform TEE exam
 - Screen for complicating pathology
 - Evaluate coronary sinus
- Place introducers
- Administer anticoagulant (e.g. heparin)
- Perform final device check

Device engagement of the CS ostium

- Direct the inner curve toward expected CS location
- Acquire device in TEE image
 - Modified bicaval (recommended) or deep 4-chamber
- Align with CS ostium using direct TEE feedback
- Engage CS ostium
- Limit initial advancement to 1-2 cm

Device advancement beyond the CS ostium

- Monitor advancement (fast-frame fluoroscopy)
 - Desired track is left-superior
- Non-occlusive venography (continuous fluoroscopy)
 - Assess device depth and CS diameter
- Inflate balloon to the first plausible end-point
 - Onset of "ventricularization" trace
 - Diameter match on fluoro
 - Predicted volume
- Occlusive venography
 - Distribution of retrograde injection
- Note presence of extravasation or staining

Pre-Insertion Preparation

Pre-insertion preparation consists of a focused TEE exam, introducer placement, administration of anticoagulant (typically heparin,) and ProPleg device preparation.

Focused TEE exam

The TEE exam screens for conditions that impact the surgical plan, cardiopulmonary bypass, cardioplegia options, or ease of ProPleg device placement. It is best to recognize the need for major changes at an early point in the procedure. **Coexisting cardiac pathology** may indicate a need for modifying the operation or raise the possibility of increased surgical difficulty. Examples include unexpected valve disease or severe mitral annular calcification. **Aortic atheromatous disease** may influence the decision to employ retrograde aortic flow for cardiopulmonary bypass (CPB) or to pass guidewires into the aorta. Minimally invasive cardiac surgery routinely utilizes femoral cannulation for CPB and commonly uses devices that are positioned in the ascending aorta. **Aortic insufficiency** does not directly influence retrograde cardioplegia, but does impact the suitability of antegrade cardioplegia as the sole method of cardioplegia delivery. The severity of aortic insufficiency may influence the extent to which the clinician persists, should placement prove to be difficult.

Persistent left superior vena cava (PLSVC) can be detected with TEE [Figure 1], although diagnosis may require fluoroscopy. PLSVC is one of several possible explanations for an enlarged CS,^{6,7} however a normal CS diameter does not exclude PLSVC [Figure 4]. A coexisting left innominate vein is present in 60% of patients with PLSVC,^{8,9} and either vessel can be the dominant conduit. Injection of bubble contrast via a left arm vein may confirm the presence of PLSVC, but a negative study does not exclude PLSVC. It is logical to surmise that any PLSVC detected with TEE is probably too large to permit satisfactory retrograde cardioplegia.

The **proximal coronary sinus** can be assessed with a "deep" 4-chamber view by advancing or retroflexing the TEE probe from a standard 4-chamber view [Figure 2]. The view can be difficult to acquire if the CS is small or cardiac motion is vigorous. A prominent Eustachian valve [Figure 3] alerts the clinician that a natural ledge is present to help exclude the ProPleg device from the IVC and guide the tip into the CS ostium. The diameter and taper of the proximal CS can also be observed. Average taper of the CS is suggested by diameter differences between proximal and distal CS.

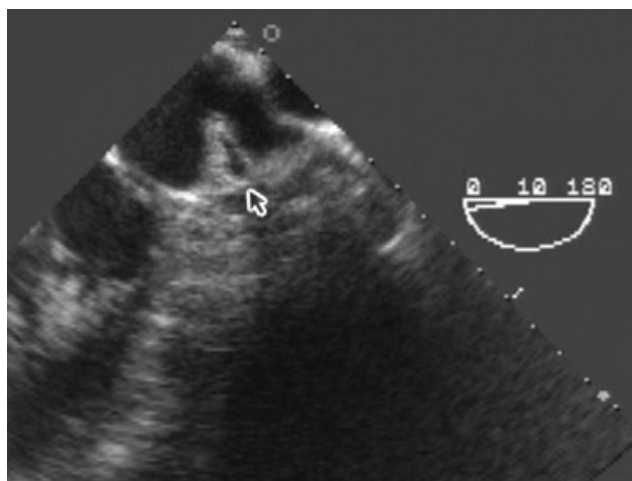


Figure 1. Persistent left SVC. PLSVC is visible in the "Coudarin ridge", anterior to the left pulmonary veins [arrow] and analogous to the (right) SVC's position anterior to the right pulmonary veins. Probe depth is slightly superior to a normal 4-chamber view.

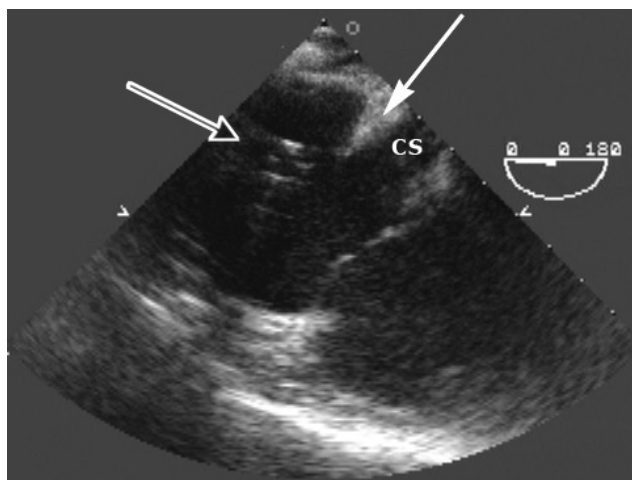


Figure 2. Deep 4-chamber view. Proximal CS diameter is ~10 mm [scale along the right edge] and without obvious taper. A femoral venous drainage cannula [open arrow] is in close proximity to the CS ostium, suggesting how a device might be dislodged. A Eustachian ridge [solid arrow] separates the lower RA and CS.

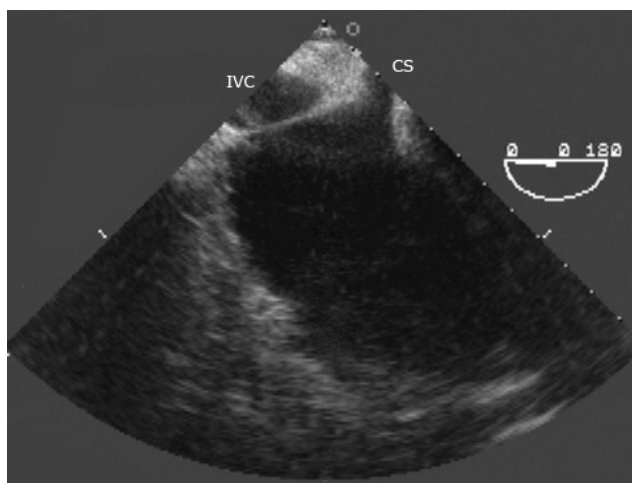


Figure 3. Deep 4-chamber view. A distinct Eustachian valve separates the IVC and CS. Significant CS taper is unlikely given the 7-8 mm ostial diameter.

The **mid to distal coronary sinus** is visible in a 2-chamber view [Figure 4]. Progressively distal segments are displayed by turning the probe further left from a 2-chamber view; more proximal segments are displayed by turning right. It is difficult to correlate a particular segment of the coronary sinus to a given degree of left-right turning. The diameter of the CS at the point of balloon occlusion determines the volume required for occlusion. Small coronary sinuses can be occluded with as little as 0.1 ml of fluid. When the “ventricularization” trace has a slow onset, continued balloon inflation can distend the sinus beyond the threshold of injury.

At some point between a 2-chamber view and the point where the TEE imaging plane intersects the left surface of the heart in tangent, the coronary sinus transitions into the great cardiac vein [Figure 5]. This view can be challenging to obtain and may be of more value after ProPledge device placement or to confirm cardioplegia flow using Color Flow Doppler mapping (CFD).

The **modified bicaval view** [Figure 6] is the preferred “working view” for engaging the CS ostium. A standard bicaval view displays the SVC and IVC; a modified bicaval view displays the SVC and CS. A narrow range of depth, multiplane angle, and left/right turning may be required to produce satisfactory images, making this view potentially difficult to acquire. Practice in a variety of patients is recommended prior to the time when the view will be needed to guide placement. Conditions that distort anatomy, including aortic root dilation and cardiac remodeling, add to the difficulty in acquiring this view.

A Thebesian valve is present at the orifice of the coronary sinus in many patients. The presence of a Thebesian valve does not necessarily imply difficulty with ProPledge device placement.

The modified bicaval view can usually be developed from a midesophageal long axis view. Probe depth is adjusted so that the aortic valve is on (or slightly above) an imaginary line drawn to bisect the imaging sector. The multiplane angle is adjusted to the lowest angle that still displays the left ventricular chamber. Turning the probe right from this position will display the modified bicaval view in a majority of patients.

Troubleshooting the modified bicaval view

If the modified bicaval view is not developed by turning right from the long axis view, three steps are followed:

- 1) confirm that the target structure is the CS,
- 2) adjust the multiplane angle to display the SVC, and
- 3) fine tune the angle, probe depth, and probe turning.

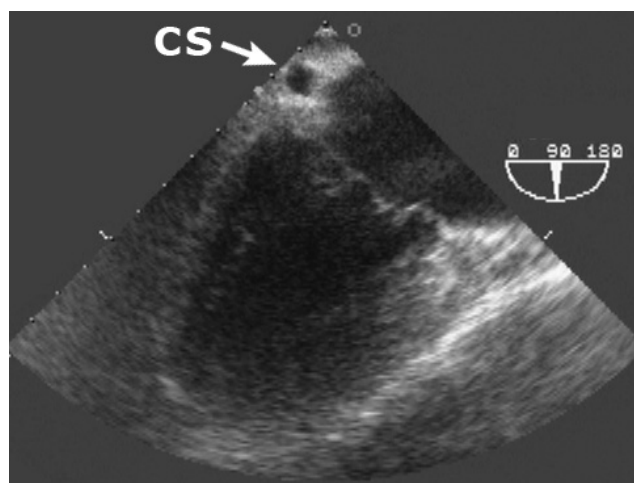


Figure 4. 2-chamber view. The CS in short axis [arrow] is ~7 mm in diameter, well within the normal range. In this particular patient, contrast injection following balloon occlusion identified a PLSVC of sufficient size to divert all retrograde cardioplegia away from the heart [Figure 54 is the corresponding fluoroscopy image]

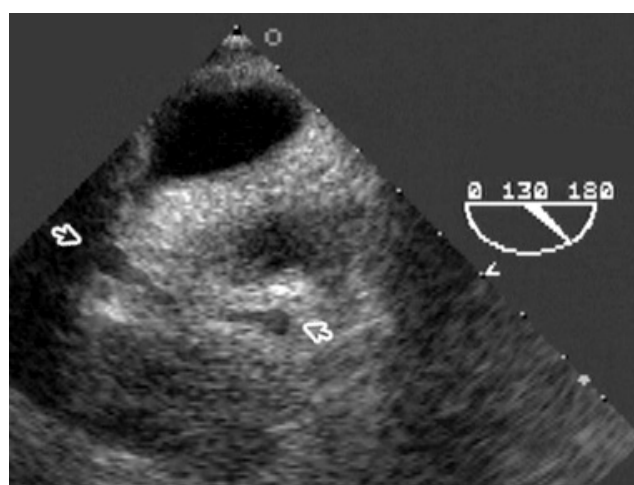


Figure 5. Left tangential view. Turning the probe further left eventually intersects the left border of the LA and LV. The great cardiac vein, the continuation of the CS, is seen here in long axis. The structures between the arrows are segments of the great cardiac vein.

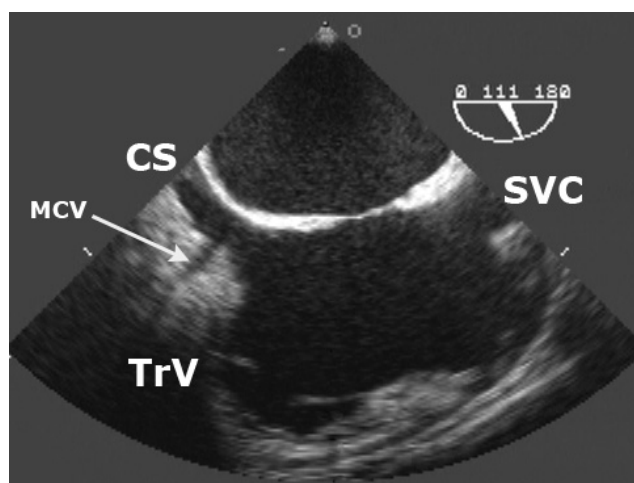


Figure 6. Modified bicaval view. The middle cardiac vein [arrow] is visible in this example. The proximity of tricuspid valve (TrV) leaflets with the CS orifice confirms target is CS instead of an off-center plane through the IVC.

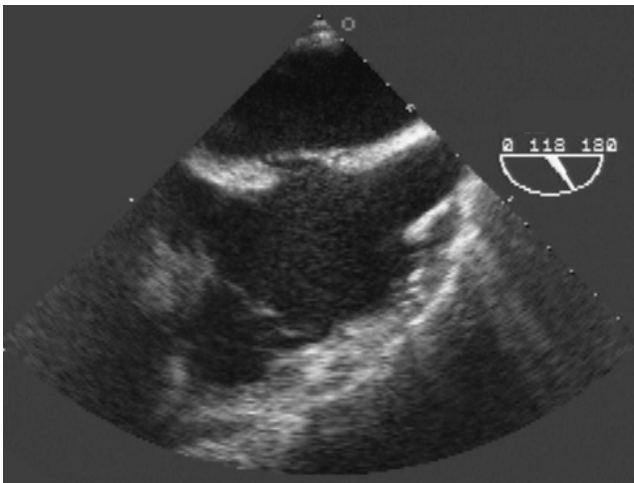


Figure 7. Modified bicaval view. Tricuspid leaflets insert near the ostium of an enlarged coronary sinus (~15 mm diameter).

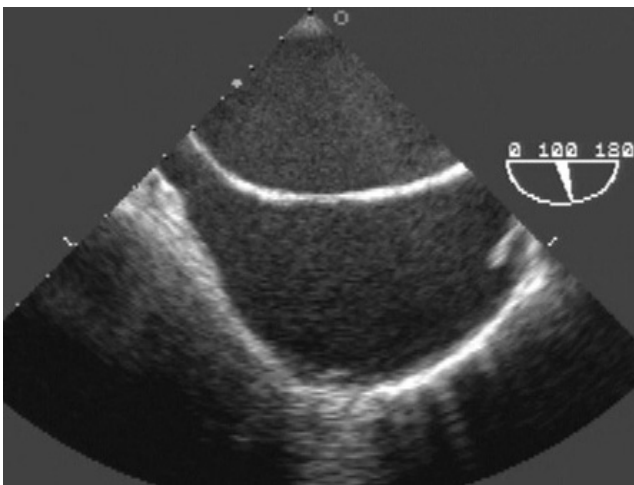


Figure 8. Equivocal modified bicaval view. There are no obvious landmarks to confirm that the structure along left edge is the CS. In this case a slight turn of the probe to the left displayed the tricuspid leaflets—inserting near the orifice of the unknown “channel”.

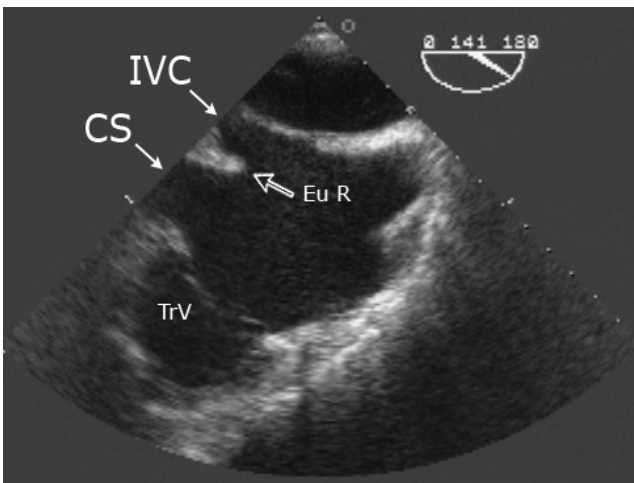


Figure 9. “Double barrel” view. The structure closer to the transducer (above) is the IVC. The structure further away (below) is the CS. In some patients only a short segment of either the IVC or CS will be seen, in others no distinct Eustachian ridge is apparent. Note that the CS is between the tricuspid valve and IVC.

Although the average IVC diameter is twice that of the average CS, diameter difference is not a reliable way to distinguish between the two. A small diameter suggests that the target is the CS, but can represent an off-center section through the IVC. When dilated coronary sinuses are also considered, there is even more overlap between IVC and CS diameters (as they may appear with TEE).

The coronary sinus can often be seen “hugging” the inferior edge of the left atrial wall (along the left edge of the imaging sector) and in some instances extends to the apex of the imaging sector. More often, only a short segment is seen of either the IVC or CS is seen. Angles of the proximal CS and IVC also overlap considerably.

A somewhat reliable TEE landmark is the **insertion of tricuspid valve leaflets** near the CS ostium [Figure 7]. If leaflet insertion is not seen [Figure 8], turning the probe slightly left will usually display tricuspid leaflets. (It is not necessary to have landmarks in view as the ProPledge device is being directed toward the CS ostium.) From the perspective of the TEE transducer, the coronary sinus ostium is positioned between the tricuspid valve and IVC. When the tricuspid valve is viewed at near-vertical multiplane angles, the CS is the first structure encountered when the probe is turned right. It is uncommon to see tricuspid leaflets inserting near the IVC orifice. The main value of this TEE landmark is reliability in acquiring a view of the tricuspid leaflets.

A second landmark is the **Eustachian ridge**. The “double barrel” view [Figure 9] can be acquired in about half of patients. The channel *above* is the IVC; the channel *below* is the CS. In many instances one or both “channels” can be represented by a small indentation. An equivalent relationship exists with the Eustachian valve. Although the CS isn’t visible in a standard bicaval view, the CS will appear in the area “below” the Eustachian valve as the probe is turned left.

A third landmark is **continuity with a known structure**. By turning the probe left to a 2-chamber view, the suspected target can be tracked as it transitions into the CS in short axis. (The effect is apparent even with the multiplane angles used for the modified bicaval view.) It may be necessary to advance the probe slightly to keep the CS in the imaging sector.

Once the identity of the coronary sinus is confirmed, the next step is to adjust the multiplane angle to display the SVC along the right edge of the imaging sector. When the SVC is not visible, an advancing ProPledge device will be out-of-plane until it nears the CS ostium. When both the SVC and CS are visible in the TEE image, tracking and manipulation of the device can begin when the device first emerges from the SVC.

The right half of the screen is examined next. If the aortic root is visible, the multiplane angle should be increased [Figure 10]. If the SVC does not reach the edge of the imaging sector, the multiplane angle should be decreased [Figure 11].

Once a passable modified bicaval view is seen, small changes in probe depth can significantly improve the view. (Changes in depth usually require compensatory adjustments to the multiplane angle.) A rough guide is to adjust probe depth so that the SVC and CS are roughly equal in length. A perfect view is not needed for placement; a balance should be struck between time expended and image quality.

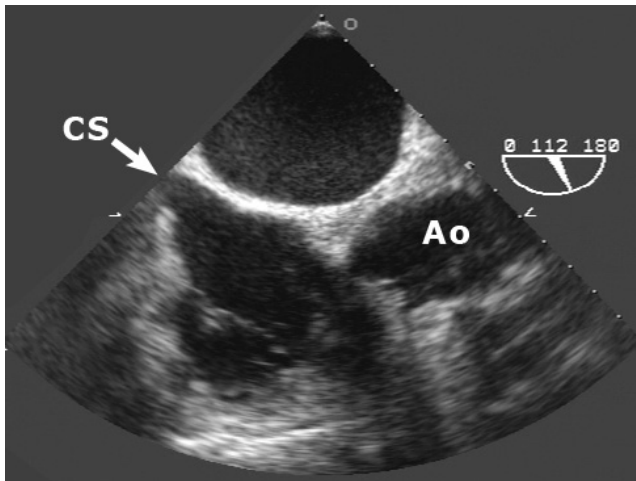


Figure 10. Multiplane angle too low. The superior half of the imaging plane is too far left, displaying the aortic root instead of the SVC. Increasing the multiplane angle will move the superior half rightward and will display the SVC. The multiplane angle of $\sim 110^\circ$ present in this case would normally produce good alignment of the SVC and CS, but is too low based on what is actually observed. Tricuspid leaflets insert near the CS ostium.

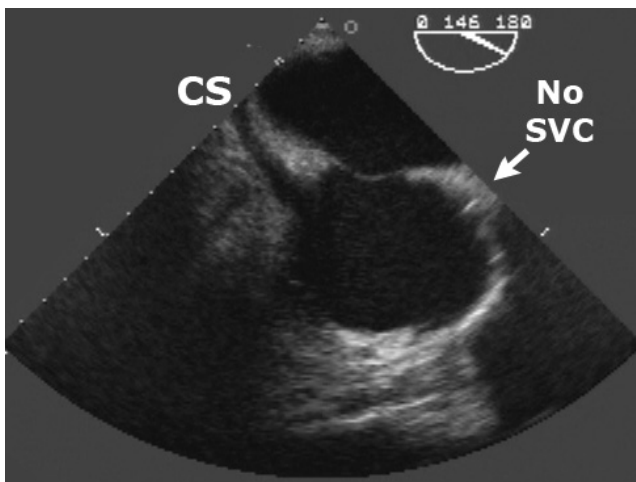


Figure 11. Multiplane angle too high. The superior half of the imaging plane is too far right. The structure in the right half of the image is that part the right atrial appendage that protrudes right of the sulcus terminalis. Decreasing the multiplane angle will bring the superior half leftward and will display the SVC. The length of the CS and position of the RA dome suggest that the TEE probe may be slightly too deep.

Introducer placement

Ultrasound screening and real-time guidance is strongly recommended for introducer placement in the right IJ vein. The left subclavian vein offers an alternative approach with a uniform arc to the CS, but may be difficult to access during surgery. Right subclavian and left IJ approaches introduce additional curves that complicate device alignment and advancement.

When multiple introducers are placed, personal experience suggests little difference in which introducer is placed proximally. A **shallow angle of entry**, e.g., under 45° , in theory reduces the potential for creating an extra curve at the point of insertion, which could alter reactions to ProPledge device manipulations. Securing with suture at two anchor sites is recommended.

Anticoagulant therapy should be administered (per hospital policy) after introducer placement and prior to device insertion. 5000 IU heparin is a common practice.

ProPledge® device preparation

A final check should precede insertion. (Initial flushing and de-airing with heparinized saline can be done in advance, often on a dedicated back table.) Stopcocks should be tightened on all ports, especially the occlusion balloon. (Loss of even a small amount of volume can result in a significant change in balloon diameter.) Flexion of the tip in response to manipulation of the positioning dial should be assessed and the position of the inner curve noted relative to the shaft's black orientation line. The black line does not need to be exactly opposite the inner curve to serve as a useful reference point, provided the precise position is observed prior to device insertion.

Sterility of the ProPledge device hub can be maintained by connecting the pressure channel to a transducer with low-compliance sterile tubing. The pressure trace should be displayed continuously while the device is in situ. A rapid method for flushing the pressure channel is to first flush to a syringe connected to the sidearm of the stopcock, and then flush the device using the syringe.

Contrast priming of the cardioplegia channel improves fluoroscopic visibility. All contrast, cardioplegia, and guidewires are introduced via the cardioplegia channel (green stopcock.) If dilute contrast (1 part contrast medium to 6 parts sterile physiologic solution, per IFU) is used for balloon inflation, the balloon should be inflated at least once with the dilute contrast mixture to prime the dead-space of the channel. The balloon should be aspirated completely flat prior to introduction, to minimize friction during device advancement in the CS.

Proplege device engagement of the CS ostium

ProPlege device engagement of the CS ostium requires the alignment of the device tip with a small target. The device is initially directed toward the expected location of the CS ostium. Once the device can be seen in the TEE image, the TEE display provides direct feedback to guide alignment of the device tip with the CS ostium. Supplemental information is provided by fluoroscopy and the pressure trace.

Initial insertion

As the ProPlege device is initially inserted, the inner curve of the device is directed toward the expected location of the CS ostium. This creates a better starting point by placing the device in (or near) the imaging plane of the modified bicaval view and also directs the device away from trabeculations in the right atrial appendage [Figure 12]. Trabeculations can catch the device tip and impede manipulation. The CS ostium, IVC orifice, and tricuspid inlet are all located in the posterior (smooth or sinus venosus) portion of the right atrium.

The CS ostium is slightly superior to the commissure formed by the septal and inferior tricuspid leaflets (at the inferior-posterior edge of the atrial septum). There are several models for visualizing this location from the perspective of a device entering via the SVC.

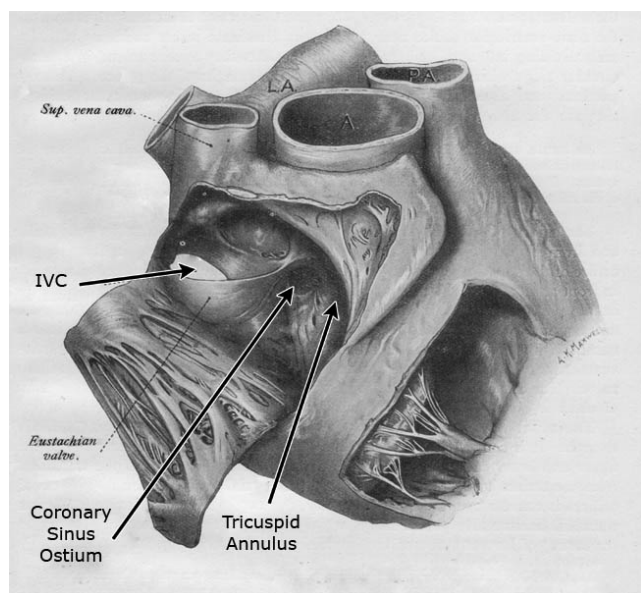


Figure 12. Exposed right atrium and right ventricle. The right-to-left arrangement of IVC-CS ostium-tricuspid valve is visible in the posterior half of the right atrium. "CS in the middle"—between the IVC and tricuspid valve—can be applied to TEE adjustments and device manipulations. The Eustachian ridge is the medial extension of the Eustachian valve. Trabeculations are visible in the atrial appendage. (From Quain's anatomy.)

One representation uses a clock face with the SVC at the center (as viewed while standing at the patient's head). In this system the expected location of the CS ostium is **7 o'clock** [Figure 13]. The same direction can alternatively be described as the "**left lower corner**" of the right atrium [Figure 14].

Initially, the device is advanced to 20 cm with no added flexion with the inner curve oriented toward the CS ostium, using the previously-noted relative position of the black orientation line as a reference. The positioning dial is then moved to the middle position, the optimal engagement position. If the device is not seen immediately on TEE, several maneuvers can bring the device into view.

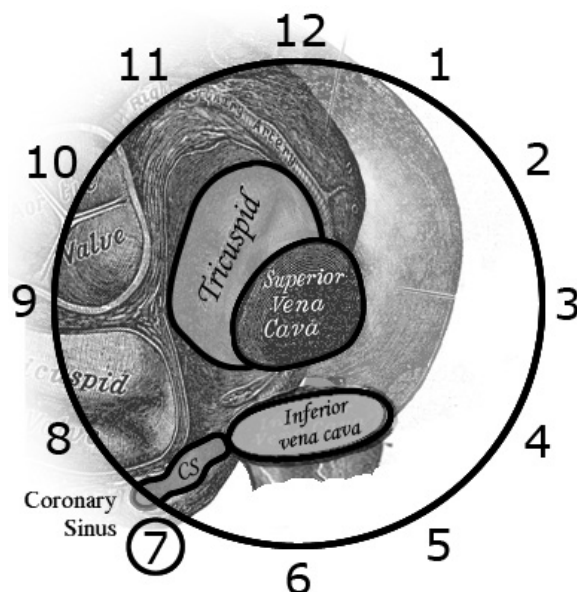


Figure 13. CS at 7 o'clock. Base of the heart from above (RA and LA removed). CS ostium is between the tricuspid valve (~8-9 o'clock) and the IVC (~6 o'clock). The complex 3-dimensional relationship between the tricuspid annulus, CS ostium, and IVC is flattened in this representation. (From plates in Gray's Anatomy)

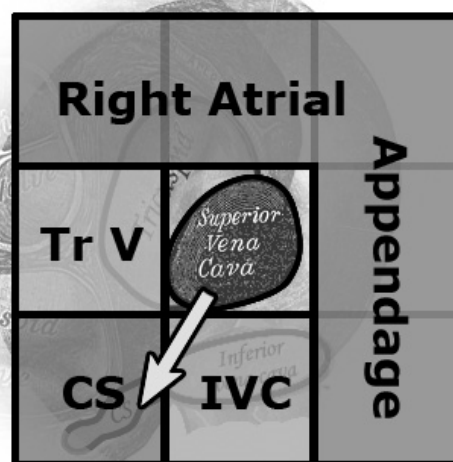


Figure 14. CS in the left lower corner. Same image as Figure 13 with a superimposed grid. Directing the inner curve of the device anterior or right engages the RA appendage.

Acquiring the device with TEE

There are empirical approaches for CS engagement that rely on withdrawing and turning a device that has been deliberately placed in either the RV or IVC. It is more productive to actively steer the device toward the CS ostium when possible. TEE is used to guide minute adjustments, which requires that the Proplege device be visible within the TEE image.

If the Proplege device was initially directed toward the expected location of the CS ostium, but is not visible at a depth of 20-30 cm, it has passed right or left of the imaging plane. The out-of-plane problem can usually be solved with one of three approaches: empirical adjustments (moving the device to the imaging plane), TEE adjustments (moving the imaging plane to the device), or fluoroscopy (revealing the device tip position relative to fluoroscopic landmarks).

Troubleshooting initial device advancement

Empirical device manipulation is an efficient first step that begins with examination of the pressure trace. If a pulsatile waveform is seen, the device tip is in the RV. A venous waveform suggests IVC cannulation, but is also seen when the device is in the RA appendage.

If the device tip is in the RV, a small degree of *counterclockwise* torque is applied prior to withdrawal of the device to the point where the waveform changes to a venous pattern. If IVC entry is suspected, a slight *clockwise* torque is applied prior to withdrawal of the device to the point where it appears (or to a depth of 20 cm). Either correction will usually cause the device to appear in the TEE image, often with the tip very near the CS ostium. If the device is not seen as a curved structure, the device tip is usually out-of-plane.³

Turning the TEE probe left or right will usually locate an errant device [Figure 15], but may *not* be an attractive option if there is no dedicated TEE person or if that person is unfamiliar with the expected TEE views. It is best to limit probe adjustments to left/right turns, since changes in the multiplane angle and/or depth can make it difficult to get back to the original modified bicaval view. A slight turn to the left will usually display the device crossing the tricuspid valve [Figure 16]. (The CS and SVC may disappear briefly during this maneuver.) Turning the probe right requires a larger turn, and when the device is seen, it is usually as a “dash” in a truncated RA or IVC [Figure 17]. Some practitioners prefer to initially direct the inner curve of the Proplege device toward an 8 o’clock position. This keeps the tip away from the IVC, since RV entry is arguably the easier of the two to troubleshoot.

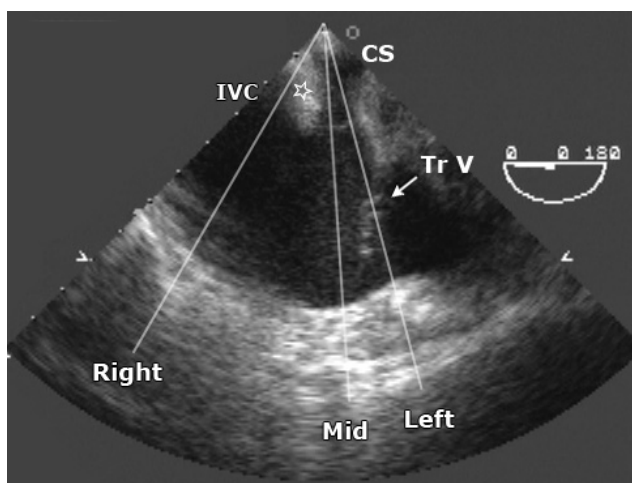


Figure 15. Deep 4-chamber view. The relative position of near-vertical imaging planes are shown as the probe is turned right to left. IVC is right, CS is mid-position, and tricuspid valve (TrV) is left. Note that a small change in arc that displays tricuspid, while a larger arc is needed to intersect the IVC [Star marks the Eustachian ridge.]

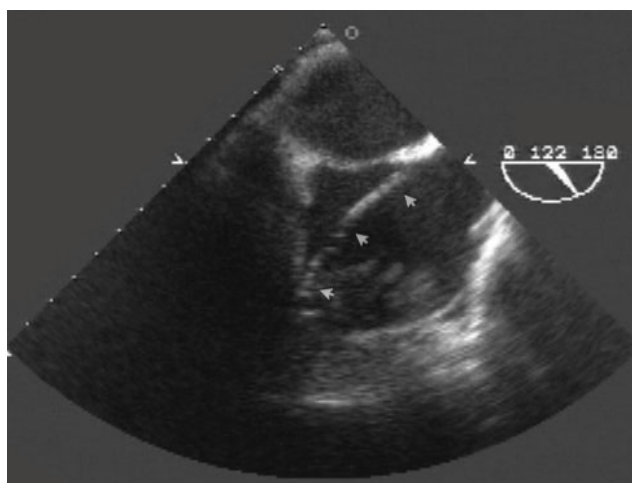


Figure 16. Modified bicaval view. The probe has been turned left from a modified bicaval view. The CS device [arrowheads] is across the tricuspid valve.

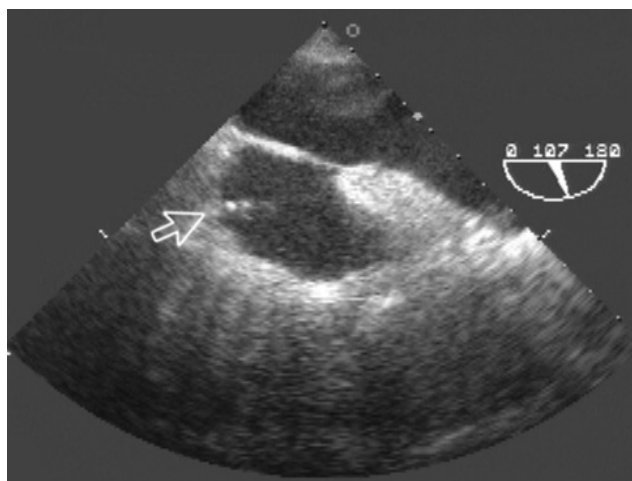


Figure 17. Proplege device in truncated RA. Typical image obtained by turning probe right from a modified bicaval view. The truncated device (dots) is indicated by the arrow. It is difficult to assess device withdrawal in this view. LA and right upper pulmonary vein are above RA.

Even when a dedicated person is available for TEE manipulation, there may be reluctance to adjust the probe if the modified bicaval view was difficult to acquire. However, there is little danger of losing the view if adjustments are limited to turning the probe left and right. Slight turns of the probe are efficient in clarifying out-of-plane misalignment of the device.

When turning the TEE probe left/right:

IVC is RIGHT
Coronary Sinus is MIDDLE
Tricuspid valve is LEFT

Fluoroscopy can be used to display ProPledge device position when other maneuvers fail. Device visibility is improved by priming the cardioplegia channel with contrast. Extended periods of fluoroscopic exposure are unnecessary; a brief “snapshot” usually will suffice. In most instances a “lost” device is in either the RAA [Figure 18] or IVC [Figure 19]. When the device tip is directed toward the patient’s right (as in the two figures), the best response often is to withdraw the device into the SVC and start over. This positions the device tip in a region where it is not inhibited by atrial trabeculations and makes it less likely that a proximal segment will be mistaken for the device tip. Torque is also transmitted better over a shorter length of device.

Fluoroscopy is good for showing the general vicinity of the device tip, but of limited use for fine-tuning device alignment. The best fluoroscopic landmarks only predict the true location of the CS ostium to within a few centimeters, which is several times the average diameter of the CS ostium.^{10,11} A PA projection is recommended for familiarity and technical ease. The CS ostium (in a PA projection) has been described as lying slightly above the diaphragm along the left border of the spine. The true position varies. One study found the CS ostium to overlie the left third of the vertebra in 25% of cases, the middle third in ~60%, the right third in ~10%, and no vertebrae in 5%.¹¹ [Figure 20]

When a deep 4-chamber view is used, the ProPledge device tip is out-of-plane when it is superior or inferior to the level of the CS, making the *direction* of the tip difficult to discern. Absence of an extra object implies a device position superior to the TEE plane; a dot implies that the tip is inferior to TEE plane. The probe should be turned sufficiently to the right to ensure that the right wall of the RA or IVC is contained within the display. Another possibility (mostly theoretical) is that the device can enter the RV superior to the level of the deep 4-chamber view. RV entry becomes apparent when the pressure trace is reviewed.

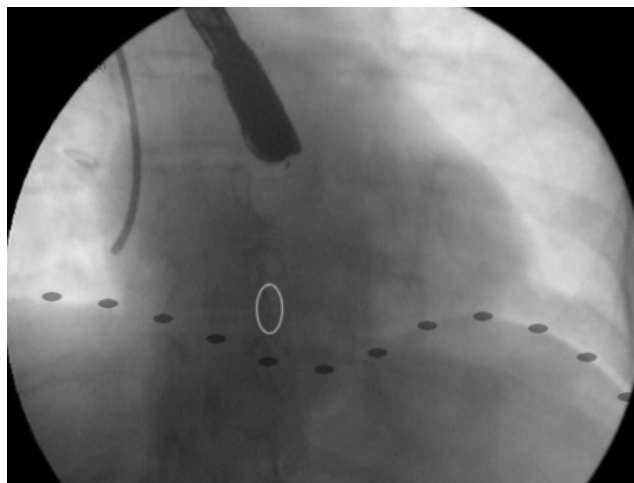


Figure 18. ProPledge device tip in the right atrial appendage. The device tip is directed toward the patient’s right. The nominal projection of the CS ostium is shown by the oval. The device tip is almost certainly in contact with RAA trabeculations.

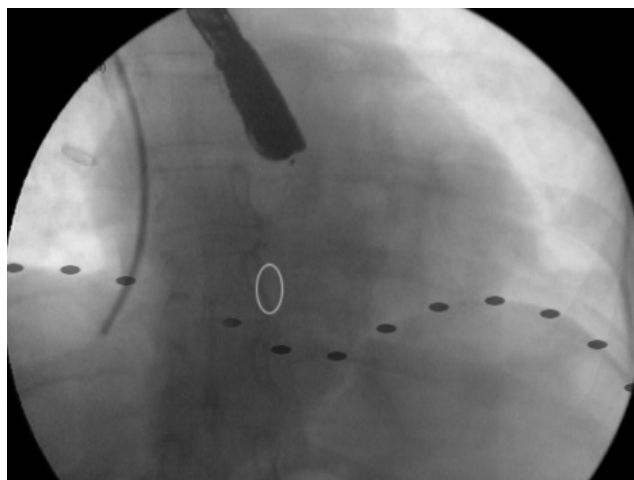


Figure 19. ProPledge device tip in the IVC. The device tip is below the diaphragm, in line with the right border of the heart. Other tracks below the diaphragm include hepatic veins [White oval is the nominal projection of CS ostium.]

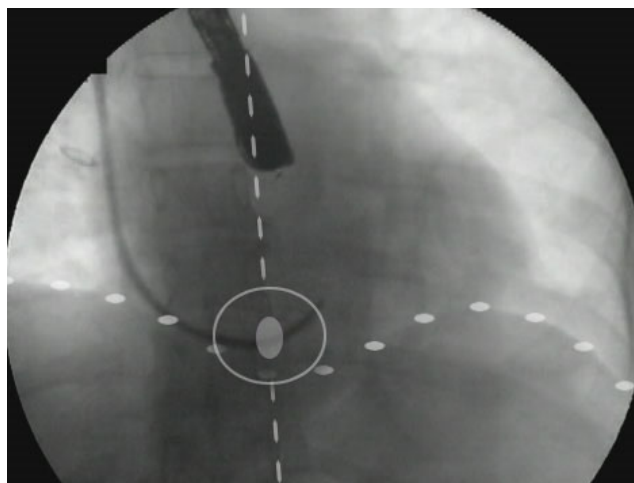


Figure 20. PA fluoroscopy. The large oval along the left border of the spine [dashed line] near the diaphragm [small ovals] is the nominal projection of the CS ostium. The elliptical line outlines 2 cm of imprecision. The tricuspid valve projection [not shown] overlaps this region.

Using TEE for direct feedback

As the ProPledge device is advanced, the course of the tip may need to change to bring it into alignment with the CS ostium. The tip turns in response to the application of torque, which can be clockwise or counterclockwise relative to the point of entry. The same spatial relationship between major structures still applies: a device directed toward the tricuspid valve must turn counterclockwise, while a device directed toward the IVC must turn clockwise [Figure 21].

Feedback can be obtained directly from either the modified bicaval [Figure 22] or deep 4-chamber views [Figure 23]. Use of the TEE display for feedback eliminates the mental overhead of noting the direction of advancement (tricuspid valve or IVC?) followed by calculation of the needed correction (counterclockwise or clockwise?).

When a **modified bicaval** view is used, torque applied directly to the device moves the device in the **opposite** direction on the TEE display. One approach is to torque the device opposite to what the display suggests is needed. Alternatively, the device can be torqued toward the direction the device is deviating away from the target. Another way to state the concept is, “Torque toward direction of the deviation.” Adjustment can begin as soon as the course of the device becomes apparent. **A common mistake is making extreme corrections. Small turns of the ProPledge device produce large turns on the TEE display.**

When a **deep 4-chamber** view is used, torque applied to the device moves the device in the **same** direction on the TEE display. The device is torqued (intuitively) toward the desired target. Another way to state the concept is, “Torque toward where you want it to go.”

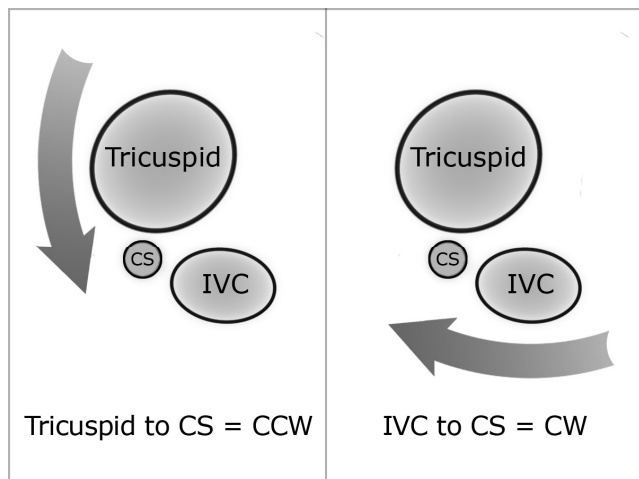


Figure 21. Directions for engaging the CS ostium. A device in the RV should have counterclockwise torque applied as it clears the tricuspid valve. A device in the IVC should have clockwise torque applied as it clears the RA-IVC junction.

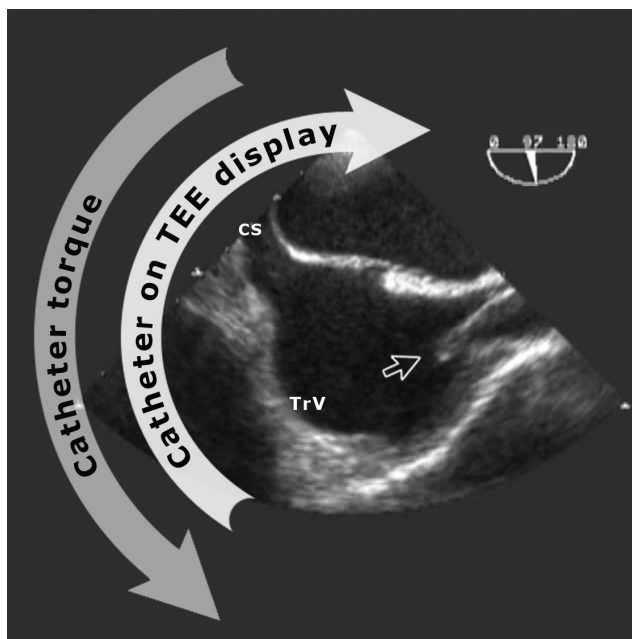


Figure 22. Direct feedback from a modified bicaval view. The device [open arrow] is advancing toward the tricuspid valve. To engage the CS ostium, it needs to be moved clockwise on the monitor. However, a device directed toward the tricuspid valve needs to be torqued counterclockwise (Figure 21). Any correction applied to the device at the point of entry moves the device in the opposite direction on the TEE display. Many people find it easier to turn toward something (compared to turning away from something). By torquing the device *toward* the direction of deviation (or variation) away from the CS, the tip will move toward the CS ostium. *Small physical adjustments applied to the device at the point of entry usually produce large changes in position on the TEE display.*

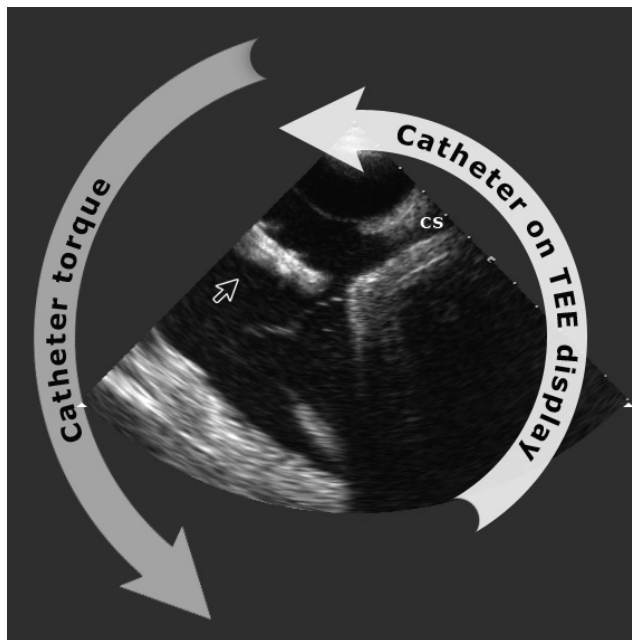


Figure 23. Direct feedback from a deep 4-chamber view. The device [open arrow] is again deviating toward the tricuspid valve. The device needs to be moved counterclockwise on the display to engage the CS ostium, which is the same direction the device must be torqued at the introducer (Figure 21). In addition to the deep 4-chamber view being more intuitive, device movement on the display correlates more closely with the magnitude of arc applied to move the device at the introducer.

Troubleshooting fine-tuning of alignment

A prominent Eustachian valve in a 4-chamber view can function as a “backstop” that helps guide the ProPledge device into the CS ostium. A device withdrawn from the RV will be less likely to overshoot the point where the device is aligned to engage the CS ostium.

Over-correction may move the device out of the imaging plane. Reversing the action will usually move the device back to the prior position. Using small corrections can help avoid the problem in the first place.

Vigorous cardiac function can cause the CS to move in and out of the plane of a deep 4-chamber view. Image quality may also be suboptimal near the diaphragmatic hiatus. Adjustments to probe depth or retroflexion can help, although a stable image cannot be obtained in some patients. The modified bicaval view is usually reliable for maintaining a stable image of the CS ostium, even with energetic cardiac motion.

The device will not react as expected when a proximal segment has been mistaken for the device tip. Proximal segments react differently than the tip, especially when the tip is constrained by RA trabeculations or the IVC.

The ProPledge balloon identifies the segment between 1.5 and 2.5 cm from the tip, but is not always visible with TEE. Inflating the balloon slightly might improve its visibility, but will likely make device advancement more difficult. A more efficient response is to use fluoroscopy when the position of the tip is uncertain.

When TEE views are unsatisfactory, the empirical “pullback” method described previously can be used. Withdrawing the device from the RV (while turning counterclockwise) is employed more commonly than withdrawal from the IVC (while turning clockwise).

Engaging the CS ostium

Once the device is aligned, it is advanced to engage the proximal CS. The positioning dial can adjust the distal curve to help align the device tip with the CS or avoid side branches, which typically join the CS on the side “away” from the apex of the TEE sector. [Figure 6]. Limiting initial advancement to 1-2 cm allows a more accurate estimation of the fluoroscopic projection of the CS ostium. The direction of device advancement using fluoroscopy and depth of impediments is easier to assess if the starting point (CS ostium) is known.

The first step following suspected engagement should be examination of the pressure trace. A venous waveform is expected with CS engagement and justifies

further advancement using fluoroscopy. A pulsatile (RV) trace rules out successful engagement. If a blunted pulsatile waveform is seen, the ProPledge device should be withdrawn *slightly* on the possibility that it may reflect close contact between the device and the CS or entry into a small diameter side branch.

It is helpful to monitor the modified bicaval view intermittently as the device is advanced. “Lifting” of the device away from the interatrial septum (IAS) usually indicates an impediment to advancement, although small degrees of separation can reflect changes in device alignment (as the device moves deeper within the CS). Temporary withdrawal often returns the device to its original position relative to the IAS.

Once the device is engaged, it can sometimes be seen within the CS by turning the probe left, although the device can be surprisingly difficult to detect when it is in close contact with the side of the coronary sinus. Scanning left will also sweep over the tricuspid valve, although the pressure trace should reveal RV entry.

Troubleshooting engaging the CS ostium

It can be difficult to detect engagement with a deep 4-chamber view when there is significant motion of the CS or when the device hugs the inferior edge of the CS. It is possible to sweep over the entire CS with a deep 4-chamber view by adjusting depth or flexion.

When the device tip disengages from the CS, it almost always enters the RV. “Dislodgment” from the CS into the IVC—especially on repeated attempts—should raise the suspicion that the IVC has been mistaken for the CS, especially when TEE landmarks are equivocal and the section through the IVC is off-center. The CS is always to the left of the IVC and can be tracked to distal segments by turning the TEE probe left.

Failure to engage the CS can be due to anatomic barriers or unusual alignment between the SVC and CS. A fenestrated or overriding Thebesian valve is uncommon. Contrast injection with the device partially engaged may reveal the problem.

Ectopy

Ectopy is common when the device tip enters (or nears) the CS ostium—presumably due to contact with the AV node or nearby conduction channels. The AV node is superior to the CS ostium, within the triangle of Koch. RV stimulation is another possible source of ectopy, but can be distinguished by the pressure trace. Ectopy associated with CS cannulation is usually limited to a few beats during initial engagement.

ProPlege device advancement beyond the CS ostium

The goal of device advancement beyond the CS ostium is to position the tip at an optimal depth while avoiding side branches and obstructions.

Opinions differ on the optimal depth for device advancement. Proximal positioning can sometimes be accomplished without the need for fluoroscopy. A balloon positioned within a few centimeters of the CS ostium can sometimes be confirmed using TEE alone.^{1,4} Distal positioning reduces the risk of device dislodgment, but is difficult to assess using TEE alone.

ProPlege device dislodgment is a potentially serious problem and merits careful consideration. A device dislodged during cardiopulmonary bypass is impossible to replace and “perfect position” at the start of the case is of little value if the device is dislodged prematurely.

Fluoroscopy offers many benefits that justify its routine use. Real-time monitoring assists navigation past obstructions and allows diagnosis of side branch cannulation. Device depth and CS diameter are easily assessed following radiopaque contrast injection. Contrast displays the eventual distribution of retrograde cardioplegia. When fluoroscopy is employed routinely, C-arm arrival can be timed to eliminate delays. Once in place, fluoroscopy reduces overall placement time by providing better information when problems are encountered. (The author uses fluoroscopy for *every* ProPlege device placement and prefers distal device positioning; radiopaque contrast is used when there is no contraindication.)

Following a brief overview of fluoroscopy, four steps of advancement will be reviewed: advancement, contrast injection, balloon inflation, and occlusive venography. TEE correlates will also be discussed.

Fluoroscopy overview

Prior to engagement of the CS ostium, fluoroscopy only reveals the *general location* of the ProPlege device. However, once the device is confined within cardiac veins, it is relatively easy to correlate a fluoroscopic projection to a given position. Radiopaque contrast injection reveals the depth and position of the ProPlege device, anatomy of the cardiac veins, and can detect evidence of cardiac vein injury.

The posteroanterior (PA) projection is recommended over left anterior oblique (LAO) projection. The PA

projection is a more familiar image for most physicians and LAO offers only minimal improvement in the accuracy of radiographic landmarks.¹¹ The metal rails on OR tables can interfere with a smooth transition between these two views, making a combined approach time-consuming.

The left border of the spine and diaphragm are easily identifiable reference points that are useful in making some general assumptions during device placement. A device tip left of the spine is likely in either the RV or CS. A device tip above the diaphragm and overlying the spine is likely in the RA. A device tip below the diaphragm is in either the IVC or a hepatic vein. The overlapping projections of the RV and LV mean that almost every position in a cardiac vein can be matched to a similar projection from a position in the RV. The pressure trace should be examined following any major change in device position to resolve the uncertainty.

A “vascular” C-arm with the ability to display the entire width and height of the heart is recommended. A “fast frame rate” of 12-15 frames/sec reduces radiation exposure and is adequate when tracking ProPlege device advancement. Continuous fluoroscopy is used for contrast injections and balloon inflation. Digital loops reduce the need for multiple injections and allow more detailed study of images. Digital subtraction is typically not used, since cardiac motion makes it difficult to get a stable background image to subtract.

Initial advancement

Limiting initial ProPlege device advancement to 1-2 cm allows fluoroscopy to be used to its maximum benefit. A few centimeters of device depth is sufficient to prevent accidental dislodgment, yet keeps the tip near the CS ostium. If the device tip is near the CS ostium when fluoroscopy is first put into use, the position of the CS ostium can be correlated to fixed landmarks. This allows more accurate estimates of the direction of device advancement and device depth.

Advancement *without fluoroscopy* can often be successful in placing the device tip in a satisfactory position (in a distal segment of the CS). However, unmonitored advancement carries a small risk of device dislodgment, injury to the CS, or injury to a side branch. Tactile resistance may not offer a true indication of the force exerted on cardiac structures. Indirect indicators of force (both TEE and fluoroscopic) should be monitored during every attempt to advance.

If the decision to use fluoroscopy has been made from the outset, it seems sensible to use it from the first point where it provides useful information.

Deeper advancement

The major focus as the ProPledge device advances beyond the CS ostium is the direction of advancement. The CS follows the projection of the posterior AV groove, which is predominantly left/superior relative to the CS ostium. **Left-superior tracking** is consistent with tracking within the CS [Figure 24], but overlaps other positions including the RVOT [Figure 25].

The initial course of the CS can be horizontal for the first few centimeters (and can even dip slightly inferior) before turning left-superior. The AV groove eventually reaches the left edge of the mitral annulus and turns anterior to pass under the LA appendage. The overall course is perpendicular to the major axis of the heart.

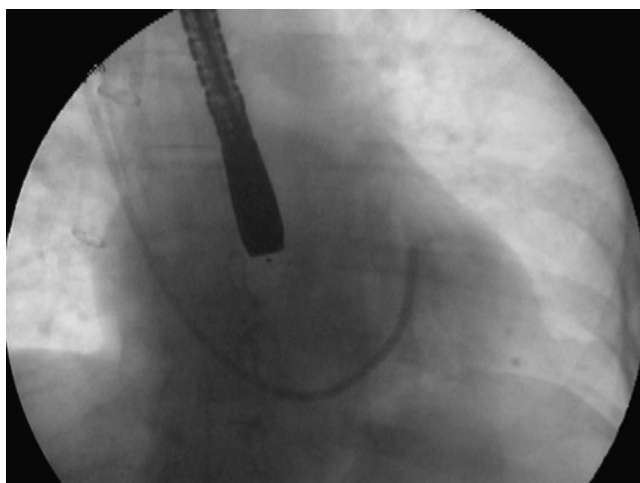


Figure 24. ProPledge device in distal CS. The device has advanced along a left-superior track. A venous waveform was present, suggesting CS cannulation. Contrast injection confirmed CS placement.

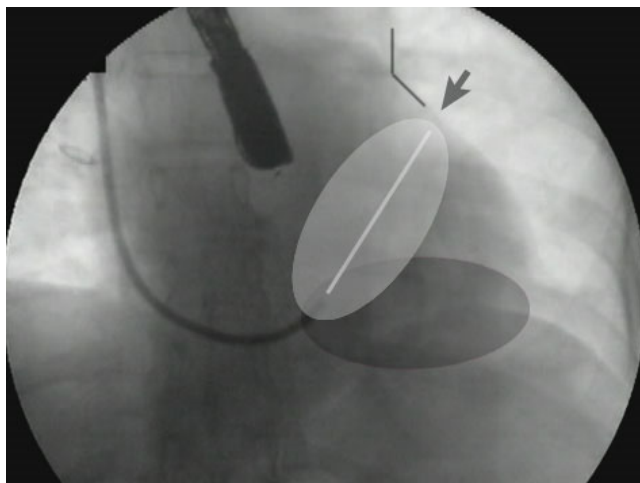


Figure 26. Tracking zones. The target for advancement is 1-2 cm below the angle formed by the PA and left border of the heart [arrow]. The straight line should not be taken literally—the device often follows an arc that is concave superiorly. Apical tracking [darker oval] is usually the middle cardiac vein or RV apex, but is “wrong” in all but a few cases of severe cardiac remodeling, e.g., patients with a huge left atrium. The left double lumen tube can be seen to have been misplaced in the right mainstem bronchus.

The shadow of the LA appendage may not be apparent in many patients. A substitute target for advancement is the point a few centimeters “below” the angle formed by the PA and the left heart border [Figure 26]. Left-superior tracking describes a *region*, not a discrete line. Although the track is commonly a relatively direct path, it may follow the “indirect” route of a gradual arc (concave superiorly) that only turns left-superior after starting horizontally for the first few centimeters.

An apical track (typically left-inferior) usually indicates cannulation of the middle cardiac vein [Figure 27], but can also be seen when the device is in the RV apex. An apical track can initially be difficult to distinguish from a device following the variation of an initial horizontal path.

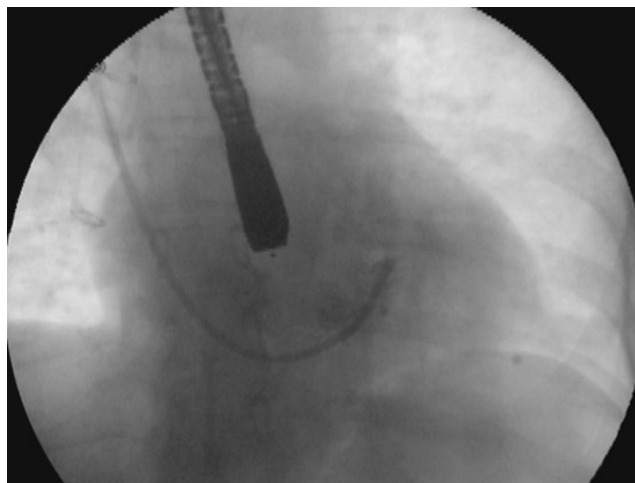


Figure 25. ProPledge device in the RV outflow tract. The faint, wispy lines around the tip are contrast. Examination of the pressure trace would have revealed RV entry and saved an unnecessary injection of radiopaque contrast.

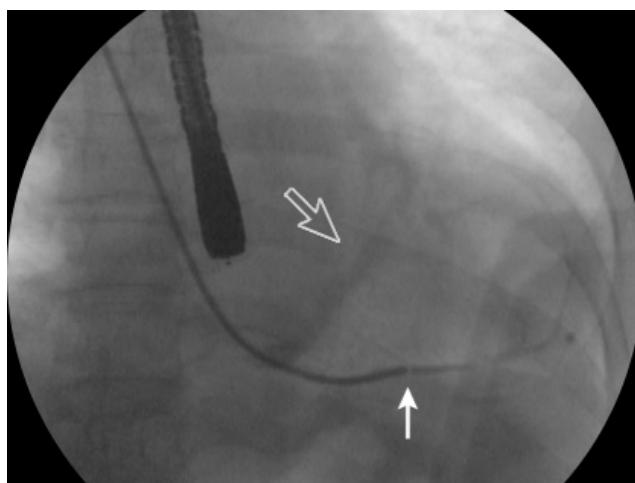


Figure 27. ProPledge device in middle cardiac vein. The device tip [solid arrow] is in a middle cardiac vein. Contrast spreading via the venous plexus of the heart helps to identify the CS as a faint shadow [open arrow]. Balloon inflation or continued advancement in a vessel of this caliber can result in injury. The outlines of the CS and middle cardiac vein correlate well with the regions identified in Figure 26 at the immediate left.

The angle of advancement is sometimes intermediate between apical and left-superior paths. In addition to normal variations in the orientation of the heart, the device can cannulate a posterior ventricular branch if it joins the CS at an angle more shallow than normal [Figure 28]. Posterior ventricular branches normally join the CS several centimeters distal to the CS ostium at oblique angles that approach 90°. A shallow posterior ventricular branch should be considered when device advancement is blocked half the distance between the spine and left border of the heart. (Definitive diagnosis and troubleshooting are discussed later.) An intermediate angle of advancement can be seen when the AV groove has been distorted by cardiac remodeling [Figure 29], but can also be observed in patients with relatively normal anatomy. Contrast injection may ultimately be required to clarify device position.

A steeper-than-expected angle can be seen in patients with abnormal cardiac orientations [Figure 30]. In other instances the ProPledge device is following the course set by the proximal curve of the CS device. Device advancement can be impeded if the distal CS turns away from this established vertical path. Contrast injection will sometimes show a CS with a “kinked” appearance [Figure 31]. (Diagnosis and troubleshooting are discussed later.)

Vigorous device excursion following advancement suggests CS cannulation. However, the dependence of device motion on underlying cardiac function makes it an unreliable discriminator of device position. **The pressure trace should always be examined to clarify position, regardless of how “obvious” it is that the ProPledge device has entered the CS.**

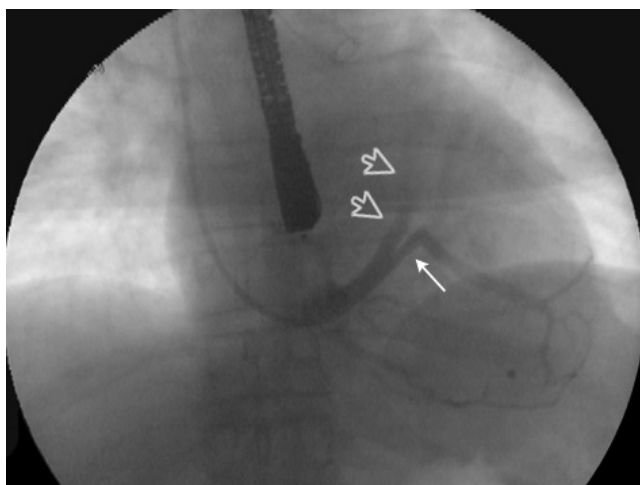


Figure 28. ProPledge device in a shallow posterior ventricular branch [solid arrow] This condition was considered as a possibility when advance of the device halted abruptly. The 90° turn of contrast toward the cardiac apex is typical for shallow-angled posterior ventricular branches. Collaterals fill a “ghost” of the CS [open arrows] and the middle cardiac vein (which empties near the CS ostium).

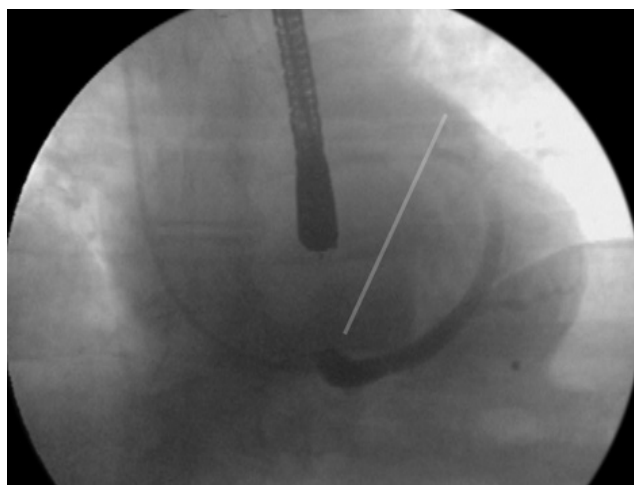


Figure 29. Variant CS projection. The device was initially thought to be tracking in a side branch until contrast injection confirmed CS cannulation. The “theoretical” direct path [faint line] is shown for comparison to the true course. The patient had severe LA enlargement due to chronic mitral regurgitation (6 x 6.5 cm).



Figure 30. Vertical AV groove in a “horizontal” heart. A kinked CS was suspected prior to occlusive venography. Contrast instead showed the almost-vertical course of the CS [arrow]. The atrioventricular groove is roughly perpendicular to the major axis of the heart.

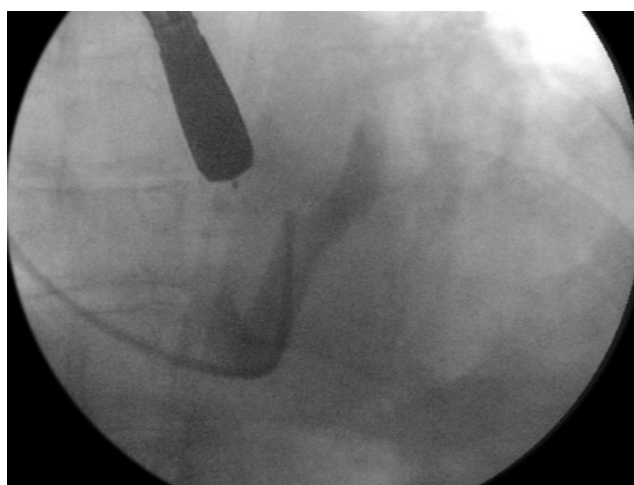


Figure 31. Kinking of the CS. Another vertical track, but this time the device is following a vertical path established by the interactions between the device and proximal segments of CS.

If the ProPleg device does not advance readily, small adjustments (turning left/right \pm advance/withdraw) are usually effective in bypassing most impediments. The modified bicaval view only provides a *qualitative* indication of impeded advancement [Figure 32], since the hang-up can exist at any point between the CS ostium and the target depth.

In addition to the direction of device advancement, fluoroscopy shows device depth during advancement within the CS. When the tip is not making expected progress, attention should also be paid to *bowing* in proximal segments and the *direction of the device tip*.

When the tip is hindered, additional lengths of device form a curve in the right atrium [Figure 33]. The device tip pivots at the point of the hang-up, pointing progressively counterclockwise on the fluoroscopy display: initially pointing left-superior, then vertical, and eventually right-superior [Figures 33 & 34]. The worsening alignment between the device and the CS makes it unproductive to feed additional lengths of device and persistent efforts can result in either dislodgment (common) or CS injury (rare). Some degree of bowing is often unavoidable, since small degrees of force may be required to achieve advancement. However, continued advancement in the face of exaggerated bowing wastes time and risks injury to the relatively thin-walled¹² CS and side branches.

Gradual withdrawal under fluoroscopic guidance will eventually restore the more productive left-superior orientation of the device tip [Figure 34]. Once the tip is properly directed toward the patient's left shoulder, readvancement is more likely to be effective.

If repeated attempts fail, contrast injection will usually clarify the nature of the obstruction. Examination of the pressure trace and gentle aspiration (free flow excludes an obstacle to injection) should precede injection of a few milliliters of radiopaque contrast. Temporary balloon occlusion may be necessary if the initial spread of contrast does not clarify the problem. Temporary inflation in a side branch is not inherently harmful, provided that proper precautions (see below) are taken.

The tentative endpoint for advancement is influenced by factors such as the suitability of antegrade cardioplegia as an alternative to retrograde cardioplegia (should dislodgment occur.) The increased stiffness of the ProPleg device design helps reduce dislodgment by resisting migration during cardioplegia administration. Compared to earlier devices, the author now accepts a more shallow position, with the proximal edge of the balloon 2 cm or more beyond the CS ostium. Final adjustment is made following routine contrast injection.

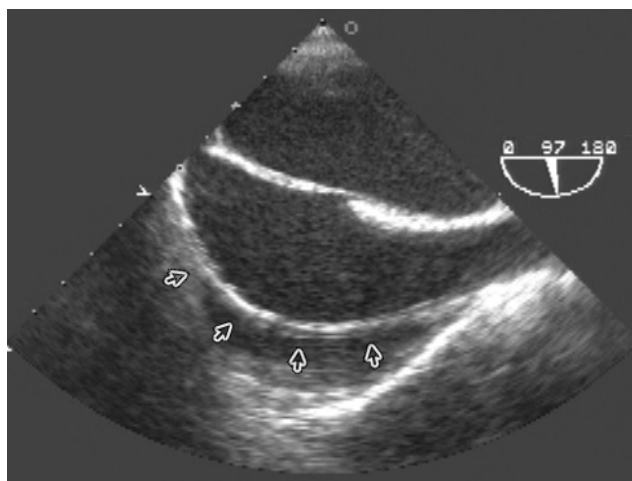


Figure 32. ProPleg device bowing (TEE). Device [arrows] lifts away from IAS. Small changes in IAS separation as the device tracks deeper in the CS may only reflect changes in alignment between the device and the CS.

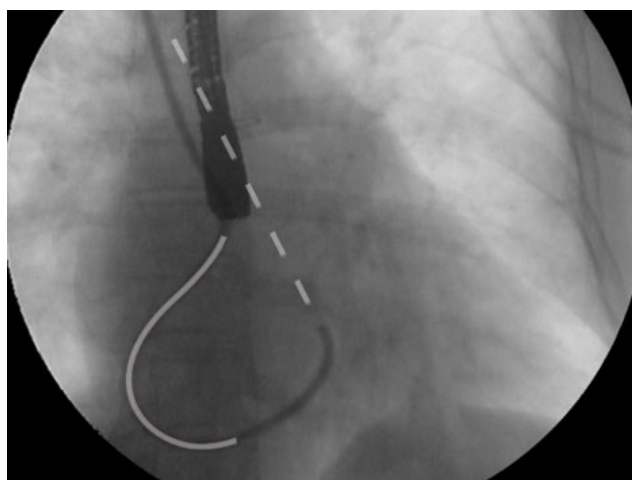


Figure 33. ProPleg device bowing (fluoro). The device tip is pointing toward the patient's right shoulder [dashed line] and there is bowing in the right atrium [solid curved line]

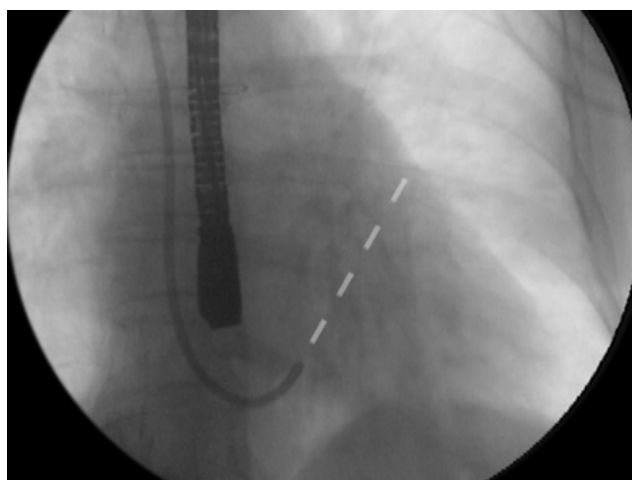


Figure 34. ProPleg device tip aligned for advancement. (The image above, after withdrawing the device to remove bowing and align the tip.) The tip is pointing left-superior as desired [dashed line]. Small manipulations will usually help to advance the device past minor obstructions. The contrast injection in Figure 41 revealed the needed alignment by revealing the overall course of the CS.

The position of the CS ostium can be derived from the fluoroscopic projection at the time of initial CS engagement or may be estimated as either the point where the ProPledge device crosses the left border of the spine or the point of maximum convexity [Figure 35]. Maximum convexity is the point at which the device begins to curve superiorly again and has been found to be within ~1 cm of the CS ostium (0.8 ± 0.6 cm range 0.2-2.2 cm).¹¹

Device depth can be estimated using the TEE probe (~1 cm in diameter) or vertebral bodies (~3-4 cm wide in a PA projection) as references for distance. CS diameter should be assessed 2 cm proximal to the tip, since that is the point where the balloon contacts the vessel wall. Since cardioplegia administration requires occlusion, the “functional depth” of the device is 2 cm less than the depth of the tip.

As the coronary sinus approaches the left edge of the heart, it begins to curve anteriorly. Although the projection of the CS is accurately displayed when the ProPledge device tip is in the proximal and mid CS, the leftward component diminishes as the CS begins to course anteriorly.

Real-time feedback using TEE alone is limited—it is difficult to monitor for bowing and simultaneously scan distal segments of the CS. Assessment of CS device position may have to be made *after the fact* when TEE is the sole imaging modality in use. It is acceptable to turn the TEE probe left from the modified bicaval view without adjusting the multiplane angle—a precise vertical imaging plane is not necessary. It can be

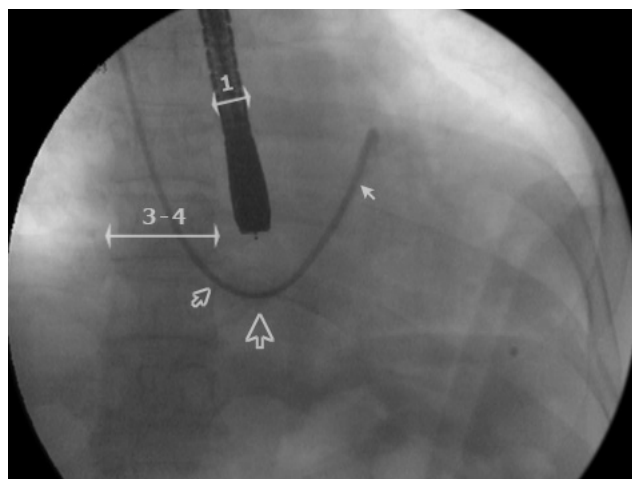


Figure 35. Fluoroscopic references for ProPledge device depth. The left border of the spine [small open arrow] and point of maximum convexity [large open arrow] have been correlated with the position of the CS ostium in a PA projection. Brackets identify reliable structures for estimating dimensions: vertebral bodies ~3-4 cm; TEE probes ~1 cm diameter. Balloon contact is 2 cm proximal to the tip [solid arrow].

surprising difficult to detect the device in all segments of the CS with TEE. Even when the tip can be identified, it is difficult to correlate to a specific depth within the CS using TEE alone. The device can (variably) be identified in a 2-chamber view [Figure 36] and/or a “tangential view” [Figure 37]. As the TEE probe is turned left from a 2-chamber view, the coronary sinus and great cardiac vein—which begin on opposite sides above the mitral annulus—approach each other until they converge in an image of the CS in long axis. Adjustment of the multiplane angle may be required to track the CS as the probe is turned left.

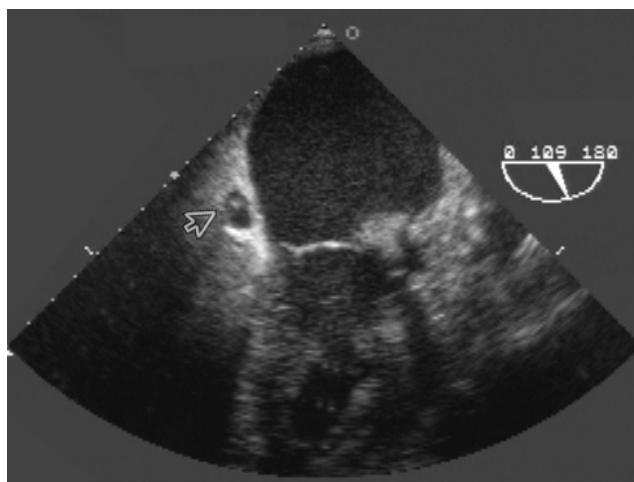


Figure 36. 2-chamber view of a ProPledge device in the distal CS. The device is not always easily identifiable, even when a short axis view of the CS is easily acquired. Sometimes there is image drop-out; at other times close contact between the device and CS makes it difficult to identify the device with certainty. Panning over the CS (by turning the probe slightly left or right) can improve device detection, but does not solve the problem of correlating a given degree of turning to a specific device depth.

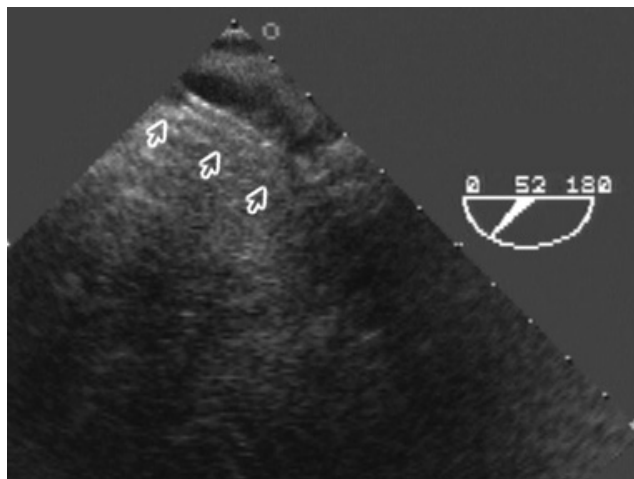


Figure 37. Tangential view of a device in the distal CS. The probe is turned to the point where it intersects the left border of the heart in tangent. The coronary sinus and a device are visible in long axis. The device depth can be assumed to be at least moderate; a precise position is difficult to assess. (As the probe turns far left, there is a significant parallax component. A slight turn further left often displays the descending thoracic aorta.) This view is similar to what would have been obtained by turning the probe further left in Figure 5.

Troubleshooting advancement beyond the CS ostium

Advancement problems can be divided into side branch cannulation and impediments to advancement. **Contrast injection is often the first step in clarifying the underlying problem.** Injection-related injuries are rare provided that there is a venous waveform and aspiration (or opening the stopcock) confirms free flow.

Side branches should be suspected with apical tracks (middle cardiac vein) or impeded advancement at mid-depths along an intermediate track (shallow posterior ventricular branch). With a shallow posterior ventricular branch, the ProPlege device tip will halt at the point where the vessel takes a sharp turn toward the apex. An unfavorable curve in the device may result in repeated cannulation of side branches [Figure 38].

Adjustments in the distal curve can optimize device engagement and advancement. Major side branches of the CS generally originate from the cardiac apex. A tighter curve (smaller radius) can help direct the device tip away from side branches [Figure 39]. However, too small a radius may predispose the device tip to disengagement instead of advancement.

While prior versions of this monograph discussed reshaping prior versions of the device, the current IFU strongly cautions against manipulating the ProPlege device to modify the factory-applied curve. All adjustments to the distal curve are accomplished solely via the positioning dial [Figure 40]. Overcorrection in either direction can sometimes impede advancement. If the device fails to advance, adjustment of the curve in either direction will sometimes improve success. Deflation of the balloon should be done prior to insertion, but is worth repeating if friction is deemed to be a contributing factor. Although counter-intuitive, an often-successful step is to withdraw the device slightly before reattempting advancement. This can either create better alignment with the CS or disengage the device from side branches.

During the initial learning phase, engaging the CS ostium is a challenge. With experience, engaging the CS ostium becomes straightforward and most problems are related to advancing the device beyond the CS ostium. Removing a device that is “already” a few centimeters inside the coronary sinus may seem to be a counterproductive action, but may be necessary to improve alignment with the CS or avoid side branches.

Some anatomic variants make advancement difficult. If the coronary sinus makes a sharp turn superiorly at a point where a side branch joins the sinus, it can be almost impossible to avoid entering the side branch.¹³

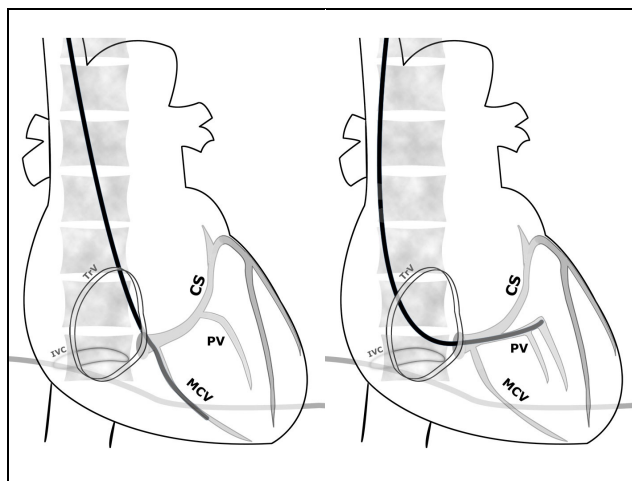


Figure 38. ProPlege device engaging side branches. The radius of the distal device can favor engagement of the middle cardiac vein (left) or a shallow posterior ventricular branch (right). (The posterior ventricular branch in the left image is the more common angle between the CS and PV.)

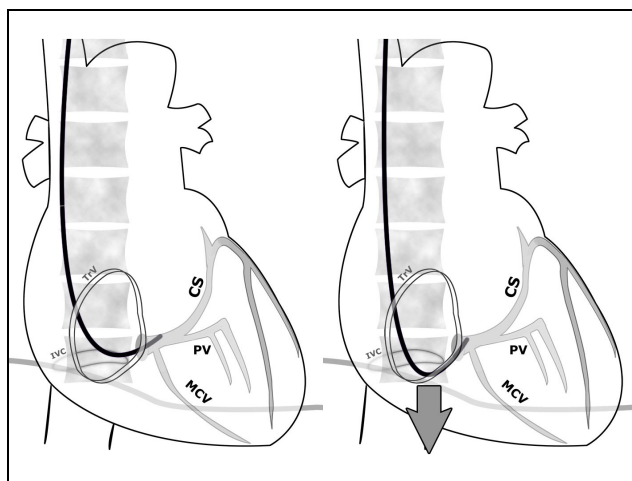


Figure 39. Modified curve of the distal device. The smaller radius on the left favors advancement into the distal CS. The excessively small radius on the right may result in dislodgment as advancement is attempted.

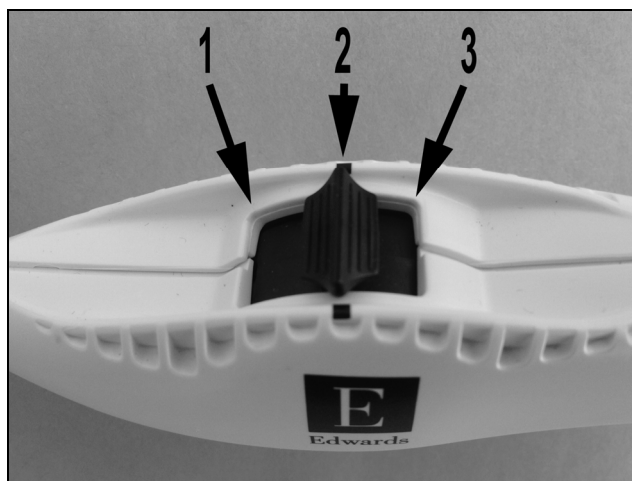


Figure 40. The positioning dial on the ProPlege™ handle. Position “1” flattens the curve (larger radius) and is used during introduction. Position “2” aligns with a black mark and is usually optimal for engagement. Position “3” creates a sharper curve (smaller radius) when additional articulation is needed.

Impeded advancement sometimes appears to be caused by friction between the CS and the ProPledge device tip. Contrast injection will show a “kink” in the CS in many such instances. The key finding is that the device tip is no longer aligned with the lumen of the CS. The angle of the kink can be subtle [Figure 41], but is typically steeper (more superior) than normal. A steep angle may raise suspicion, but contrast injection is often required to distinguish an atypical cardiac orientation [Figure 30] from a kinked coronary sinus [Figure 42].

Standard maneuvers should be repeated first. If the device is at a sufficient depth, slight withdrawal may result in a satisfactory final position with no vessel deformation [Figure 43]. If CS kinking occurs at shallow depth, advancement beyond the obstruction is usually desirable. One solution is to bypass the obstruction with a guidewire [Figure 44], and then advance the device over the guidewire. A hydrophilic coated, soft-tip 0.035" (0.89 mm) guidewire (minimum length 100 cm) is recommended (see IFU.) The cardioplegia stopcock is opened to all 3 arms after capping the sidearm (pathway for contrast injection) and attaching the supplied hemostasis valve. The device should be withdrawn slightly (until the device is no longer in close contact with the CS) *before the guidewire emerges* to reduce the potential for injury. This also creates a space for the guidewire's J-tip to deploy and greater freedom for the guidewire to bypass the obstruction.

Guidewire advancement often requires the same maneuvers used for device advancement. Use of a guidewire adds a small risk of vessel injury and should be reserved for cases where achieving greater depth is judged to be worthwhile (after standard methods fail).

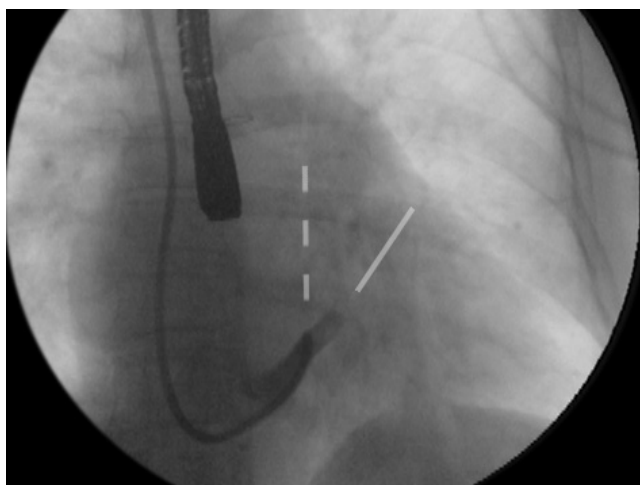


Figure 41. Subtle kinking of the CS. Contrast injection shows the device tip to be in contact with the superior edge of the CS at a relatively shallow device depth. The direction of the device tip [dashed line] is not aligned with the distal CS [solid line]. This is the same patient in Figures 33 & 34 (used to illustrate signs of impeded advancement). Standard corrections were ultimately successful in advancing the device to a greater depth.

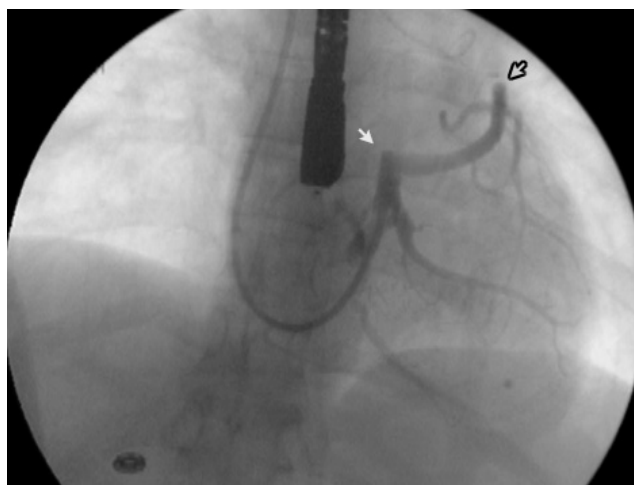


Figure 42. "Kinking" of CS. The device is in contact with the coronary sinus at an angle that no longer favors distal tracking [solid arrow]. Indenting of the thin-walled CS is sometimes seen. Contrast extends to the left border of the heart, confirming CS placement [open arrow]

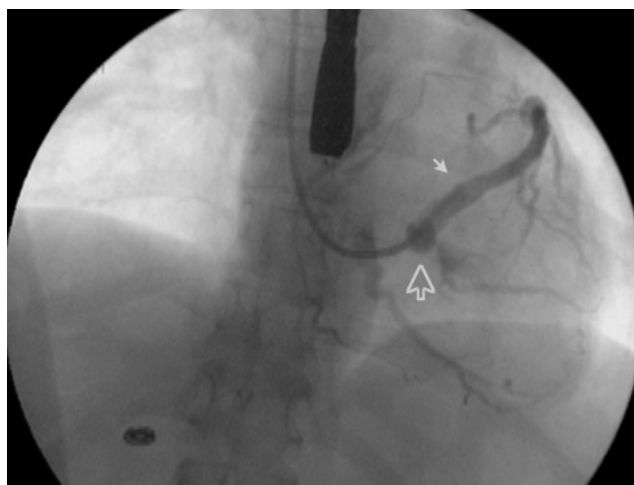


Figure 43. Kinking solved by ProPledge device withdrawal. Patient above after slight device withdrawal. The depth and distribution of contrast support proceeding with this depth as a final position [arrows mark tip and balloon]

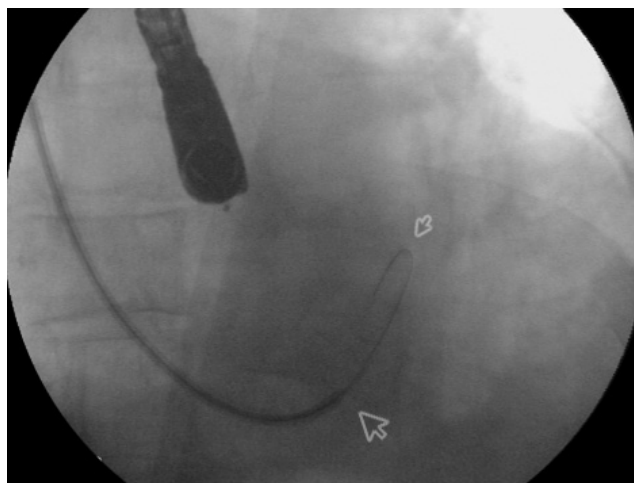


Figure 44. Guidewire advanced to bypass kinking. The guidewire [small arrow] has bypassed the obstruction. The device tip [large arrow] was withdrawn ~2cm to create a space for guidewire deployment and navigation.

Advancement can also be limited by an impassable valve in the CS [Figure 45]. In the author's series, valves could not be bypassed by guidewires or ProPledge device manipulation in ~1% of patients. Valves may have been present in other patients, but remained undetected, when advancement was successful.

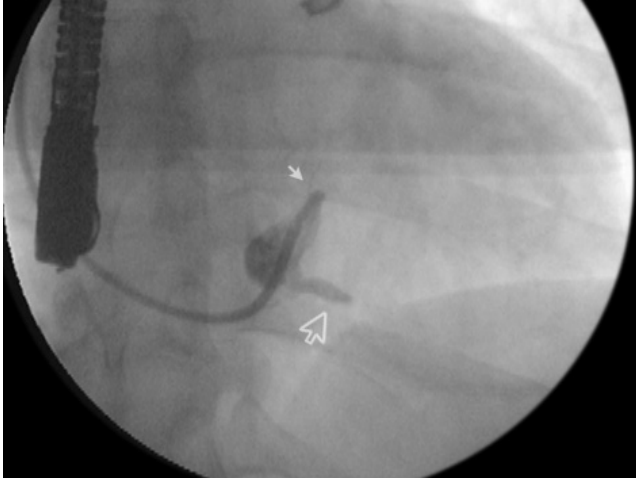


Figure 45. Valve in the coronary sinus. Filling of the coronary sinus halts at the valve [small arrow]. Partial filling of the middle cardiac vein is observed [large arrow]. Somewhat surprisingly, the TEE 2-chamber view of the device tip was similar to successful placements.

Contrast injection (Non-occlusive venography)

“Non-occlusive venography” is **contrast injection with the balloon deflated** and is used to fine-tune ProPledge device depth and predict balloon volume. Minimal contrast volumes, injected moderately rapidly, are often the most informative. Non-occlusive venography shows **device position** (CS vs. a side branch), **CS shape** (tapered vs. cylindrical), **CS diameter** (measured 2 cm proximal to tip), and **device depth** (CS ostium to device tip) [Figure 46]. Contrast displays CS and side branch position, shape, and diameter. Most coronary sinuses have a slight amount of clinically insignificant taper in the first few centimeters.¹⁴ The 3 mm diameter of the 9 Fr device can be used as a reference for estimating CS diameter. Device depth can be reassessed once the CS ostium is identified (as the point where contrast is diluted by RA blood). Contrast injection should be repeated following any consequential repositioning.

A device in a side branch can often be repositioned into the CS by withdrawing the device proximal to the origin of the side branch, and then applying standard manipulations. It may be desirable to position the device to ensure perfusion of a significant posterior ventricular branch [Figure 47] or to advance the balloon beyond a segment with significant taper [Figure 48].

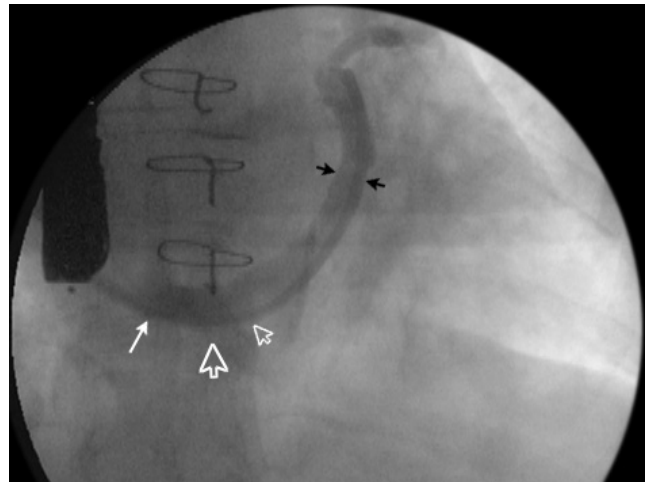


Figure 46. Non-occlusive venography. The device is relatively deep. The true CS ostium (dilation) vs. the nominal CS ostium (max. convexity, left border spine) are indicated [arrows]. CS diameter measured 2 cm proximal to the device tip [black arrows] is ~8 mm. CS has minimal taper if withdrawal is elected.

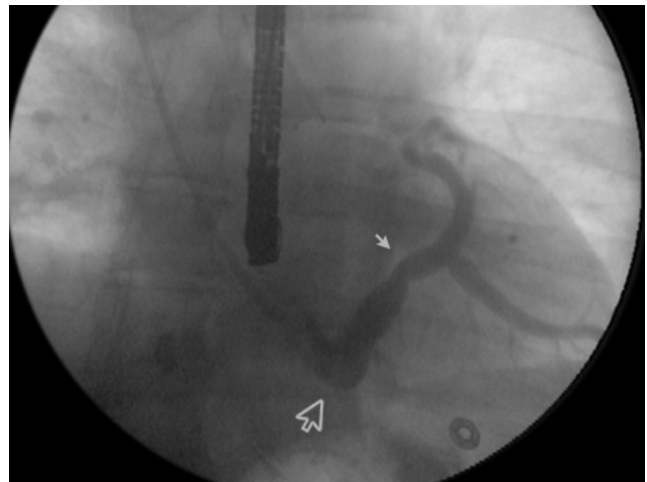


Figure 47. Large posterior ventricular (PV) branch. The device tip [small arrow] is relatively shallow. The proximal CS is slightly tapered, but shouldn't present a problem. If the device is advanced, final balloon position should be proximal to the large PV branch (which joins the CS at a more typical oblique angle).

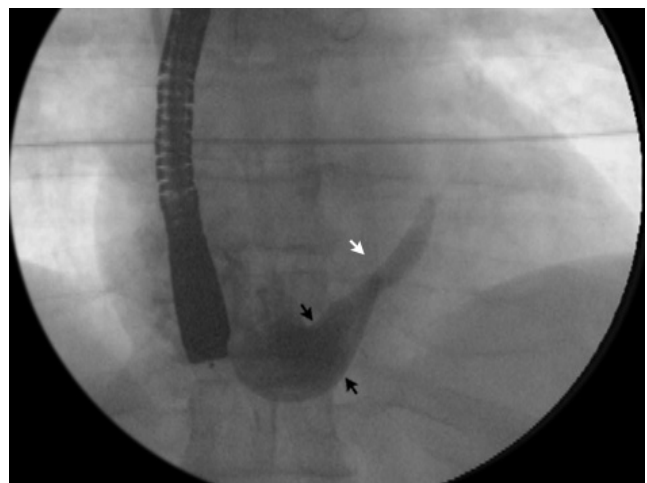


Figure 48. Severely tapered CS. Arrows show device tip and expected balloon contact. The device should be advanced to avoid loss of occlusion related to balloon migration. Note the minor misalignment between the vector of device tip and the distal CS.

Some patients have a “windsock” shaped CS—the first centimeter is cylindrically dilated and tapers beyond that point.¹⁰ A large CS orifice makes engagement easier but can complicate device management. Pressure distal to the balloon (created by normal venous drainage or cardioplegia administration) has the potential to move the balloon toward the CS ostium. If the balloon migrates to a segment with a larger diameter, the mismatch between balloon and CS diameters can result in loss of occlusion. Positioning the balloon beyond a tapered segment minimizes the impact of minor degrees of migration. It is logical that a significant conical shape might predispose the balloon to migration, due to changes in the way the balloon contacts the vessel wall.

It is useful to correlate the point of contrast dilution (the CS ostium) to fixed fluoroscopic landmarks that are visible *without* contrast. The thoracic spine and “point of maximum convexity” are suitable markers for the CS ostium. Rib borders are convenient reference points for assessing changes in tip position.

Final device position is ultimately a medical decision that may be a compromise between “the optimal” and “the satisfactory”. Even experienced practitioners may fail to achieve the preferred target within an acceptable time period. Continued efforts may offer little additional chance of success with increased risk of injury.

Balloon inflation (CS occlusion)

Non-occlusive venography precedes balloon inflation so that the diameter and position of the CS can be assessed. (TEE can estimate CS diameter in the approximate vicinity of balloon inflation but is limited in warning of impending inflation in a side branch.) Fluoroscopy allows the clinician to minimize the risk of over-inflation by using the information obtained during non-occlusive venography to predict and monitor balloon inflation. Balloon occlusion volume can vary substantially between patients [Figures 49a and 49b].

Gradual balloon inflation (while monitoring the pressure trace) provides some degree of safety, but is not foolproof. The appearance of the “ventricularization” trace is typically gradual and can set the stage for over-inflation, particularly when the coronary sinus is small. The largest *absolute* increase in diameter occurs during initial inflation. The balloon is deformable at 0.1 ml, but spherical beyond 0.2 ml. Volumes of 0.1-0.4 ml correspond to balloon diameters of 6-10 mm—the normal range of CS diameters. The graph at the right plots *measured* diameters versus injected volume.

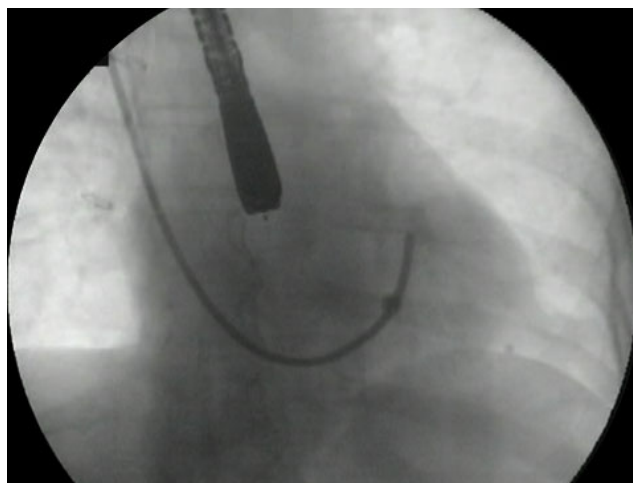


Figure 49a. Balloon occlusion in a small CS. Balloon diameter at occlusion is ~6 mm with a balloon inflation volume of ~0.1 ml.

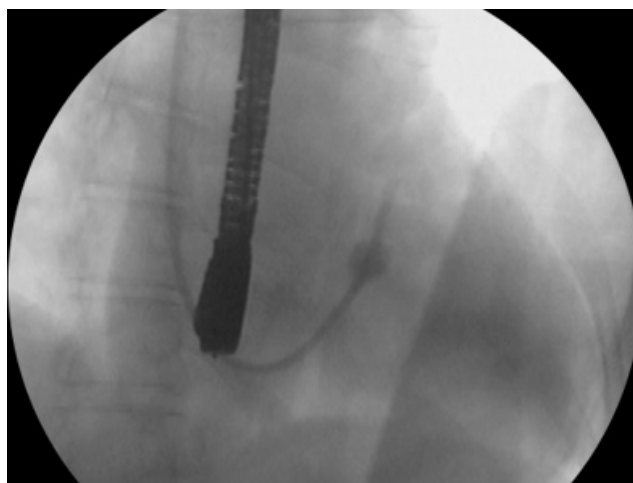


Figure 49b. Balloon occlusion in a large CS. Balloon diameter at occlusion is ~12 mm with a balloon inflation volume of ~0.8 ml. The distance from the ProPleg device tip to the ostial side of the balloon is 2.5 cm in both images.

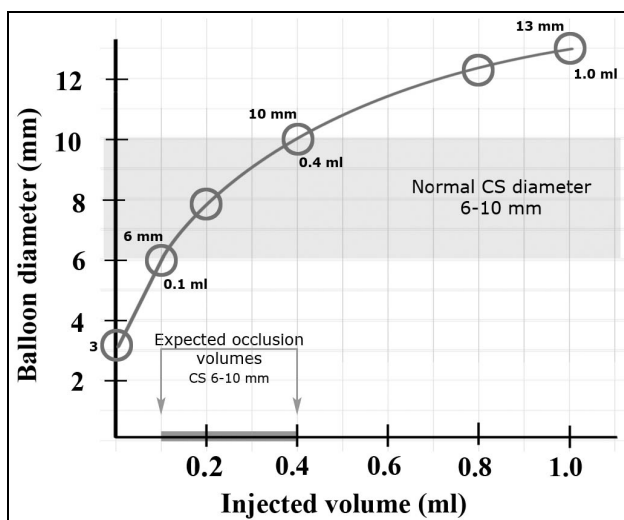


Figure 50. Balloon diameter during inflation. Diameter rises rapidly during initial inflation, and then flattens out.

The calculated volumes include the volume of a 3-mm diameter cylindrical device subtended by a spherical balloon, but still illustrate the non-linear slope of diameter-vs-volume. Diameters rounded to nearest mm. Consult manufacturer’s data for current *in vitro* dimensions.

The balloon diameter is monitored with continuous fluoroscopy as it is slowly inflated with dilute contrast. Injection is halted at any of four end points: 1) a **visual match** between the diameter of the expanding balloon and the CS diameter observed during non-occlusive venography, 2) the **onset of a ventricularization pattern**, 3) the **predicted volume** predicted by the observed diameter of the CS, or 4) the **maximum recommended volume** (currently 1.4 ml—consult the IFU). It is easy to add more volume if the balloon is short of occlusion, but an injury can't be undone.

Detection of a visual match may be aided by displaying a still frame from the non-occlusive venogram on a screen adjacent to real-time fluoroscopy.

A ventricularization trace is the desired end-point and signals occlusion of the CS. Alternate endpoints are recommended because a ventricularization trace builds over several seconds or more, making it difficult to appreciate the moment of occlusion [Figure 51]. The amplitude continues to build without the addition of volume. A low pressure scale aids detection of the initial change. Although most patients tolerate some CS distension, the exact extent is difficult to predict. Continued inflation risks over-distension without the benefit of improved occlusion.

Predicted volume can be approximated with this rule:

*0.1 ml doubles the 3 mm diameter of a 9 Fr device.
Each 2 mm increase in diameter doubles the volume.*

CS dia. 2 cm proximal (mm)	Required volume (ml)
3	0
6	0.1
8	0.2
10	0.4
12	0.8

[Shading of the 0.1-0.4 ml inflation volume corresponds with the 6-10 mm range for normal CS diameters.]

A 1 ml syringe would increase precision but reduces the ability to detect high syringe pressures. (The author uses a Luer-Lok 3 ml syringe with 0.1 ml graduations.)

The syringe volume at occlusion should be noted for future inflations during cardioplegia.

The balloon sometimes migrates toward the CS ostium during inflation. ProPlege device bowing or balloon contact with the vessel wall usually limits the displacement. Balloon expulsion during this stage is uncommon and depends upon the magnitude of upstream flow, CS shape, and diameter. Balloon expulsion is more likely when retrograde cardioplegia is initiated at too a high a rate—before the balloon becomes anchored by contact with the vessel wall.

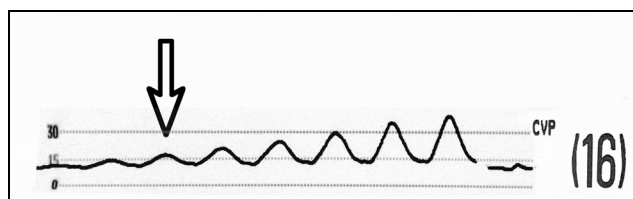


Figure 51. Gradual onset of the ventricularization trace. Although balloon inflation was halted at the arrow, the amplitude continued to increase. Continued inflation would most likely not alter the extent of occlusion, while increasing the risk of CS injury related to balloon over-inflation.

Occlusive venography (Retrograde contrast)

Following satisfactory occlusion, radiopaque contrast is injected while the balloon remains inflated. Continued injection will outline cardiac veins [Figure 52]. The great cardiac vein and middle cardiac vein are consistently present as branches of the coronary sinus.¹⁵ Posterior ventricular and marginal branches are variably present.

If contrast reaches the left border of the heart, it confirms cannulation of the coronary sinus. When contrast turns toward the apex *before* reaching the left border of the heart, it indicates side branch cannulation.

After reaching the left border of the heart, contrast should turn toward the cardiac apex and fill numerous side branches via collaterals. The middle cardiac vein (which typically has an almost horizontal course) fills before emptying into the CS (proximal to point of balloon occlusion). The CS ostium is again displayed as the point where contrast is diluted by blood in the right atrium.

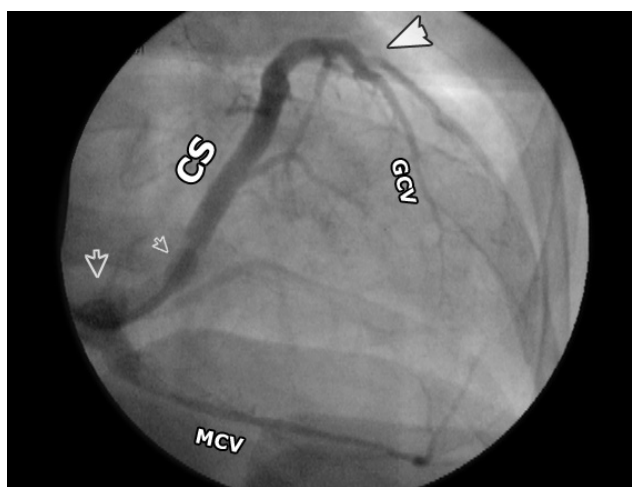


Figure 52. Occlusive venography. Radiopaque contrast was injected with the balloon inflated. The balloon [small open arrow] migrated during inflation, but is still 2+ cm from the CS ostium [large open arrow]. Contrast extends to the left border of the heart [solid arrowhead], then turns toward the apex. CS = coronary sinus, GCV = great cardiac vein, MCV = middle cardiac vein. A marginal branch and 2 small posterior ventricular branches are also present in this patient.

A small leak around the balloon is acceptable if a ventricularization trace is observed [Figure 53]. The seal between the balloon and vessel wall does not need to be water-tight to deliver effective cardioplegia.

Occlusive venography mimics the spread of retrograde cardioplegia, excludes the presence of a PLSVC, and provides additional confirmation of ProPledge device depth. With the CS ostium displayed, device depth can be assessed in cases where the balloon migrates during inflation. The distance between the device tip and the ostial (proximal) side of the balloon is 2.5 cm.

Information obtained from contrast injection may prompt adjustments to final device depth. Multiple factors are considered, including the size and position of nearby side branches, the degree of taper near the point of balloon contact, the true location of the CS ostium (as revealed by contrast dilution), and the suitability of antegrade cardioplegia as an alternative (should the device become dislodged). When the author's team and others have compared deeply positioned percutaneous devices to standard (transatrial) retrograde techniques, post-bypass ventricular function assessed by TEE has been equivalent. The extensive venous plexus of the heart likely contributes to extensive distribution of retrograde cardioplegia.

If contrast turns superiorly after reaching the left border of the heart, and then courses along the left edge of the mediastinum, a persistent left SVC is present [Figures 54 & 55]. The relative calibers of the PLSVC and cardiac veins influence the proportional distribution of retrograde cardioplegia.

In addition to noting the distribution of contrast within cardiac veins, it should be noted whether contrast leaks from any cardiac veins. Replay of digital loops can be indispensable in detecting injuries. Contrast escaping directly into the pericardium may only appear as a brief blush. Extravasated contrast persists as "staining" when it is contained by surrounding tissue. Fixed contrast moves in parallel with the device during the cardiac cycle. Mitral annular calcification could potentially be confused with staining under certain conditions and should be noted prior to contrast injection.

In addition to tightening the locking hub of the introducer, the ProPledge device should be secured by taping the hub to the patient's forehead (with a small degree of slack in the device). The locking ring alone is not sufficient to prevent a few centimeters of movement if sufficient traction is applied to the device.

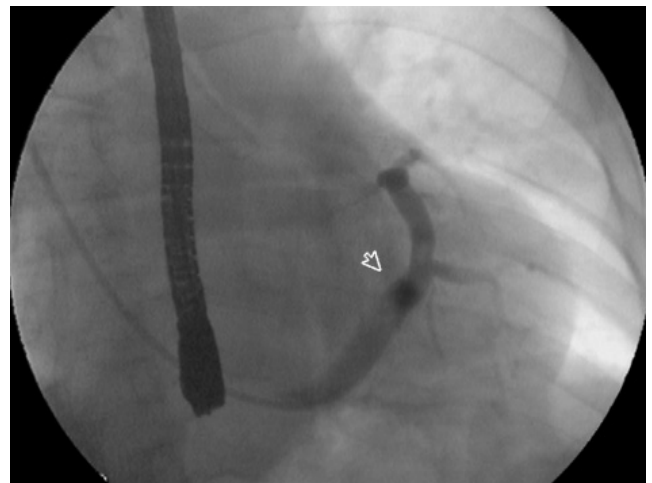


Figure 53. Small leak around the balloon. The small leak is not a major problem. Although the balloon [arrow] could be inflated slightly, the distinct outlines of side branches indicates good retrograde spread.

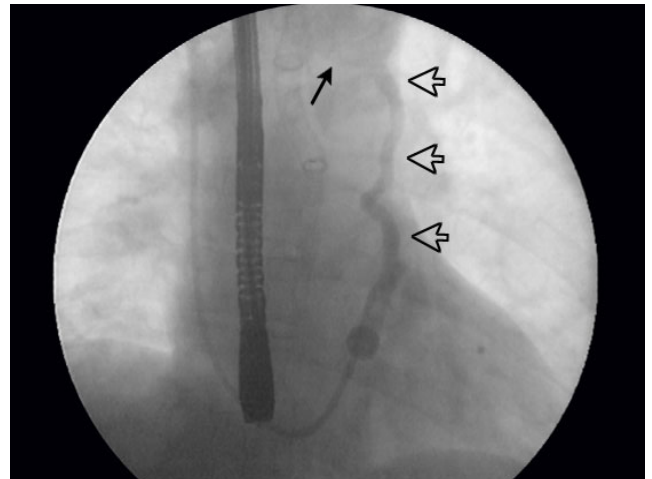


Figure 54. Small persistent left SVC. The PLSVC [open arrows] is ~6 mm in diameter, similar to the CS diameter. Essentially all of contrast passes into the left innominate vein [solid arrow]. No side branches are visible. A low resistance outlet will blunt the ventricularization trace.

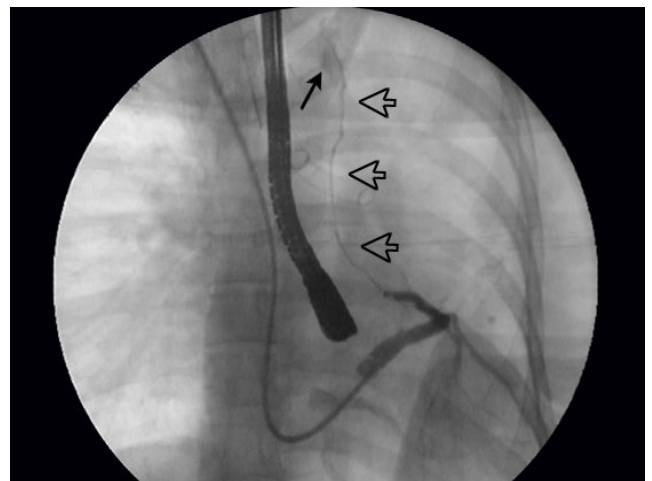


Figure 55. Very small "persistent left SVC". A 1 mm "PLSVC" [open arrows] can be seen communicating with the left innominate vein [solid arrow]. The bulk of contrast passes into the cardiac veins.

Complications and management

Retrograde coronary sinus devices are safe, reliable vehicles for retrograde cardioplegia administration. However, complications are possible and include CS injury and device dislodgment.

CS Injury

Much of the information regarding iatrogenic injury comes from reports involving attempted lead placement in distal branches of the CS.^{16,17,18} Injuries have been caused by guidewires, guiding catheters, angioplasty catheters, and PA catheters. There are significant differences in device rigidity, balloon characteristics, and other factors when these devices are compared to percutaneous devices used for retrograde cardioplegia.

Extrapolation of these reports is also limited by differences in techniques used for ProPledge device insertion and balloon inflation. However, there are some lessons that can be used to improve placement methods. The method described in this article has steps that were specifically added to minimize or detect complications [Figures 56, 57, & 58]. Some of the emphasis is intended to compensate for the reduced ability to use direct inspection when a minimally invasive approach is used.

Fluoroscopy offers the benefits of verifying device position and detecting extravasation. Balloon inflation within side branches and over-distension of the CS are recognized mechanisms of injury; they are the basis for recommending contrast injection prior to balloon inflation.¹⁸ The site of balloon inflation has been correlated as a site for CS injury in a study that cannulated the CS with Swan-Ganz catheters.¹⁶ (One significant difference is that Swan-Ganz catheters do not inflate until ~0.75 ml of air has been injected, at which point the balloon expands precipitously to an 11 mm diameter—which is the upper end of normal CS diameters.) Although most vessels will tolerate some distension, the margin of safety is unknown in a given patient. The suggestion has been made to keep the balloon/vessel ratio below 1.0.¹⁸

The spectrum of reported coronary sinus injuries ranged from minor extravasation to frank rupture. The majority involve extravasation or “staining”. Combined data from the CONTAK and MIRACLE studies (over 700 patients receiving bi-ventricular pacing leads) found staining (indicating dissection) in 2-4% of cases. True perforations were rare,^{19,20} in rough agreement with the other references in this section. Venography was essential to discover and determine the severity of CS injuries.¹⁹

“Observation” emerged as the management option following cardiac vein injury. In most reports the interventionalist completed the procedure, including instances where the wire was advanced beyond the injury.^{2,16,18,21} Long-term angiographic follow-up found no evidence of vessel damage or vessel remodeling.¹⁸ Even when subintimal dissection was caused by a device (in contrast to a guidewire), healing occurred within a few weeks.¹⁸ One offered explanation is that retrograde dissections are against downstream flow, which serves to keep a flap closed. Another contributing factor may be the low pressure in the CS (approximately equal to CVP). Resistance to advancement was not noted in some of the cases where injury occurred.

Guidewires—and even “soft” devices—can act like a stylet when they emerge from the introducing device, especially if the device and vessel are in close contact.

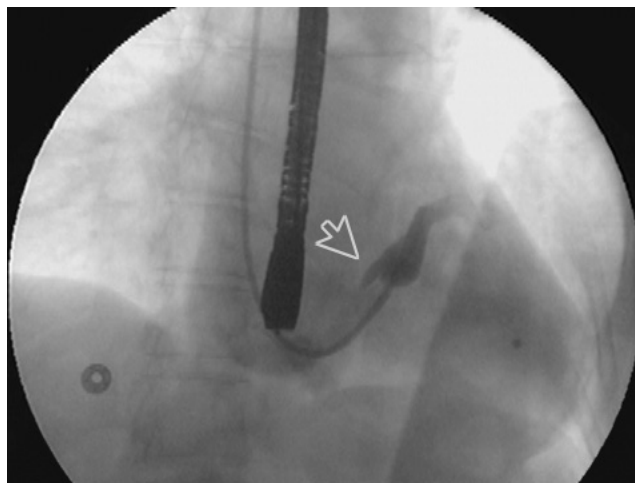


Figure 56. CS injury from balloon over-inflation. Inflation continued when a ventricularization trace didn't appear at a match in diameters. Contrast extends into a dissection plane [arrow]. The balloon/vessel ratio is >1.

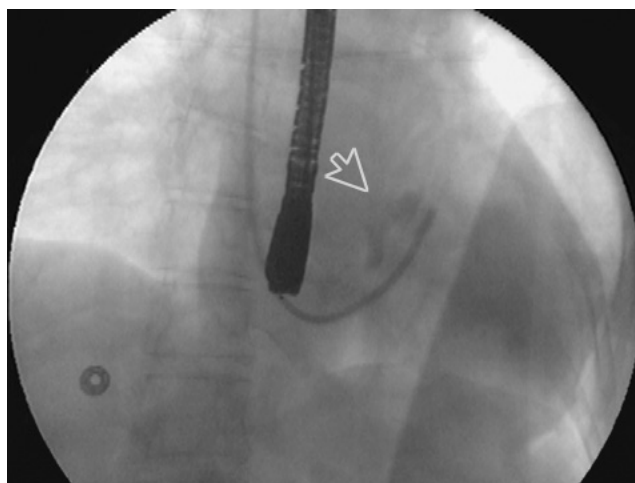


Figure 57. Image above after “dissipation” of contrast. Faint staining (extravasation) moved in parallel to the device with normal cardiac motion.

Guidewires advanced with excessive “backup support” are more likely to result in CS injury.¹⁸ A “push-pull” technique is recommended to assure that the guidewire is not bent or slack at the distal orifice. If a guidewire is used to bypass an obstruction in the CS, the guidewire should remain stationary as the ProPlege device is advanced.

Medical judgment is required when extravasation (“staining”) is detected. Some teams will use the device for retrograde cardioplegia if the balloon can be advanced beyond the point of injury. The advantages of retrograde cardioplegia should be weighed against the possibility that the device might migrate at a later point in the case (potentially exposing the injury to high pressure).

No studies have addressed the efficacy of retrograde cardioplegia delivered via a side branch of the CS. In theory the extensive cardiac venous plexus might allow adequate distribution of retrograde cardioplegia from a non-standard position, however adequate coverage can not be assumed based on current information.

RV perforation [Figure 58] has been a described complication since the early Heartport period²² and can also occur with standard PA devices and guidewires. In theory the practice of deliberately advancing the device into the RV (so that the “pullback” method can be used to engage the CS ostium) might increase the risk of incurring this complication.

ProPlege device dislodgment

Device dislodgment is infrequent, however, the close proximity of the IVC and CS ostium increases the likelihood of contact between a femoral venous cannula and the CS device. Balloon inflation prior to femoral cannula advancement is recommended to “anchor” the device within the coronary sinus. Device dislodgment during cardioplegia delivery is discussed below.

Cardioplegia administration

Resistance to flow and cardioplegia line pressure are higher when a percutaneous CS device is used (compared to a standard transatrial cannula) due to the smaller lumen and greater length.

The IFU at the time of publication states that the same technique for balloon inflation is to be followed with each cardioplegia administration, with the balloon deflated between doses. Consult the IFU for current recommendations.

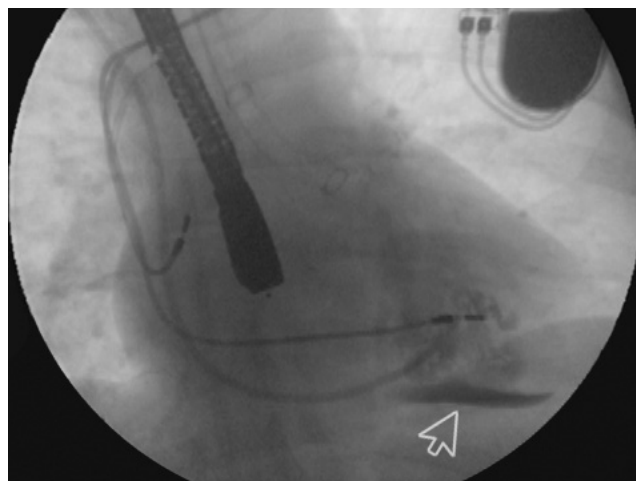


Figure 58. RV perforation. Following engagement, advancement was attempted without fluoroscopic monitoring. The device presumably disengaged from the CS ostium and entered the RV. The apical track was recognized as soon as fluoroscopy was resumed. The extra-cardiac contrast collection [arrow] is near a pacing lead in the RV apex. Although the injury could represent a middle cardiac vein perforation, the proximity to the pacing lead suggests a perforation at the RV apex.

There is no ventricularization trace during asystole, but like a ventricularization trace, the *onset* of the pressure change signals occlusion of the CS. The climb in pressure is gradual and can take several seconds to reach the equilibrium pressure. Unlike a ventricularization trace, the pressure change is a sloped line. The pressure change is only seen if cardioplegia is already flowing at the time of balloon inflation.

If cardioplegia is initiated at excessive flow rates, distal pressure can cause a partially-inflated balloon to act like a sail, displacing (or dislodging) the device before it is stabilized by contact the vessel wall. (An initial flow rate of 50 ml/min has worked well in the author’s experience.) Flow is increased after the pressure “bump” is observed. For comparison, physiologic studies have found normal coronary sinus flow to be ~100 ml/min.²³

It is often possible to visualize the device balloon with 2D TEE. Retrograde cardioplegia is commonly visible using CFD at low aliasing velocities. The “tangential view” [Figure 5] or other views at near-vertical multiplane angles are most effective in demonstrating flow in the distal CS and great cardiac vein. A probe depth near the level of the aortic valve is typical for this task with the probe is turned left to search the space between the ascending and descending aortas. Multiplane angles are typically between 60-120°.

Acknowledgments

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Appendix

Coronary Sinus Anatomy, TEE, Fluoroscopy, and Other Considerations

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Anatomy

Structures surrounding the CS ostium

The coronary sinus (CS) ostium is slightly superior and posterior to the commissure of the septal and posterior leaflets of the tricuspid valve, although there can be significant variation in the superior-inferior position along the septum [Figure A1].

The CS orifice, IVC, and tricuspid annulus are all located within the smooth (sinus venosus) portion of the right atrium (RA). The RA appendage is much more than the triangular tip that is commonly used for atrial cannulation, comprising a significant portion of the right and anterior walls of the RA. The RA appendage is demarcated internally by the crista terminalis and externally by the sulcus terminalis [Figure A2].

Within the smooth RA, the CS ostium and tricuspid inlet are divided from the IVC and fossa ovalis by a line composed (in succession) by the Eustachian valve, the Eustachian ridge, and then the tendon of Todaro, ultimately reaching the central fibrous body of the heart [Figure A3]. As the line of structures extends leftward, surface features diminish and eventually disappear.

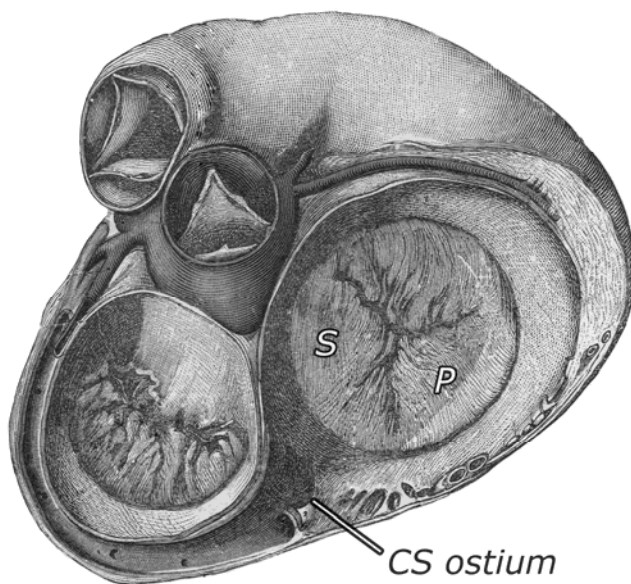


Figure A1. Base of the heart. The CS ostium is slightly superior to the commissure of the septal (S) and posterior (P) leaflets of the tricuspid valve. This image is equivalent to a deeper cut of the image at right (with the LA wall, atrial septum, and IVC removed).

Figure A2. Superior half of the right atrium. Figures 2 & 3 share a common plane of incision. (The dotted line between the figures represents a hinge.) The RA appendage in both images occupies ~180° of arc and has prominent trabeculations formed by the pectinate muscles. FO = fossa ovalis, EuV = Eustachian valve, RAA = RA appendage, MV = mitral valve, TrV = tricuspid valve. [All images on this page are from Toldt's *Atlas of Human Anatomy*]

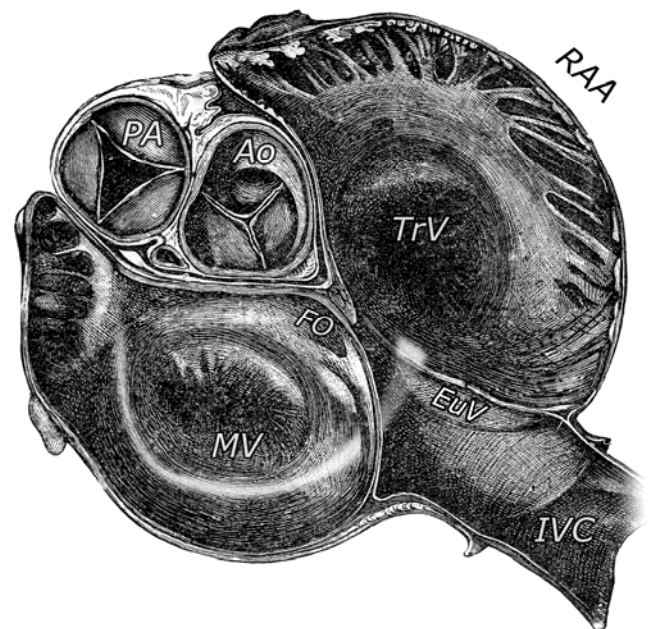
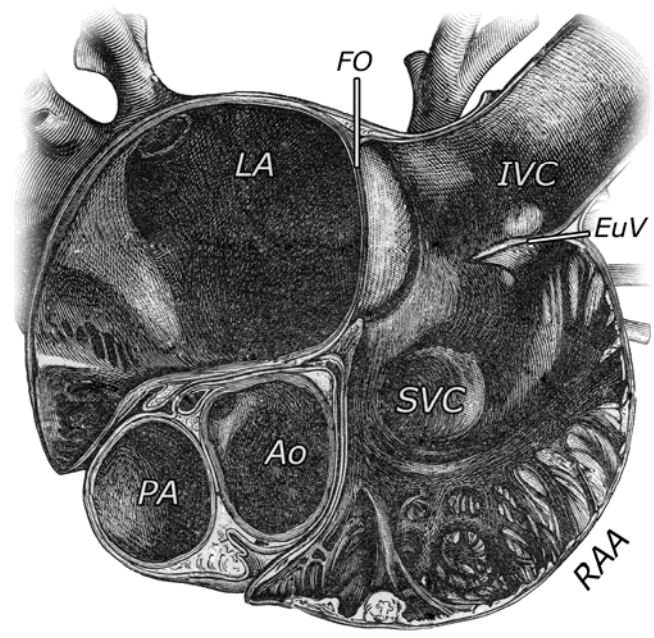


Figure A3. Inferior half of RA. The Eustachian valve/ridge is shown with exaggerated prominence but illustrates the separation of the IVC-fossa ovalis from the CS-RA infundibulum. A white band represents the projection of the CS (seen exposed in Figure A1).

When right atrial structures are viewed from the right side, a dominant feature is the position of the coronary sinus between the IVC and tricuspid valve [Figure A4]. As mentioned in the main article, this relationship is applied during TEE and catheter manipulations.

TEE images reflect the perspective of the TEE probe. The esophagus runs along the posterior wall of the left atrium (LA), most often at the midpoint of the posterior LA wall or slightly to the left of center.¹ The ability to see the IVC, CS, and tricuspid valve in the same TEE image depends on the imaging angle. When horizontal imaging planes ($\sim 0^\circ$) are used, it is almost always possible to see all three structures in a single image. In a typical deep 4-chamber view, the CS ostium is positioned between the IVC and the septal leaflet of the tricuspid valve. However, there are very few instances where vertical imaging planes ($\sim 90\text{--}130^\circ$) will intersect both the tricuspid leaflets and the IVC in a single image. This creates the TEE effect that tricuspid leaflets can be seen inserting adjacent to the CS but not next to the IVC. This effect is reinforced by the triangular isthmus in the floor of the RA. (The CS ostium is at the narrower apex on the left edge of the isthmus, while the IVC is at the wider base along the right edge.)

The ridge that separates the CS and IVC has a consistent TEE relationship relative to the IVC and CS. The ridge is part of a continuum of structures that begins at the right lateral edge of the heart and extends ultimately to the central fibrous body of the heart. Although this series of structures exists anatomically [Figure A5], it is virtually impossible to identify the complete sequence of structures with TEE. The ridge typically disappears on TEE at the point where it passes between the CS ostium and the fossa ovalis. (Consider that the transition from the interatrial septum (IAS) to the CS is typically a smooth arc in the modified bicaval view.) Even when the right atrium is opened, the subendocardial tendon of Todaro can be difficult to identify, especially in adult patients. This series of structures is also called the *sinus septum*. It is the remnant of the juncture of two embryologic veins: the right vitelline vein (which ultimately becomes the portion of the IVC above the diaphragm), and the left sinus horn (which ultimately becomes the CS).

Of related interest, the tendon of Todaro is one of the components of the triangle of Koch, the other two elements being the CS orifice and the insertion of the septal leaflet of the tricuspid valve. The triangle of Koch identifies the surface projection of the AV node. As mentioned in the main article, catheter tip contact in this area of the RA may be one mechanism for ectopy during catheter placement.

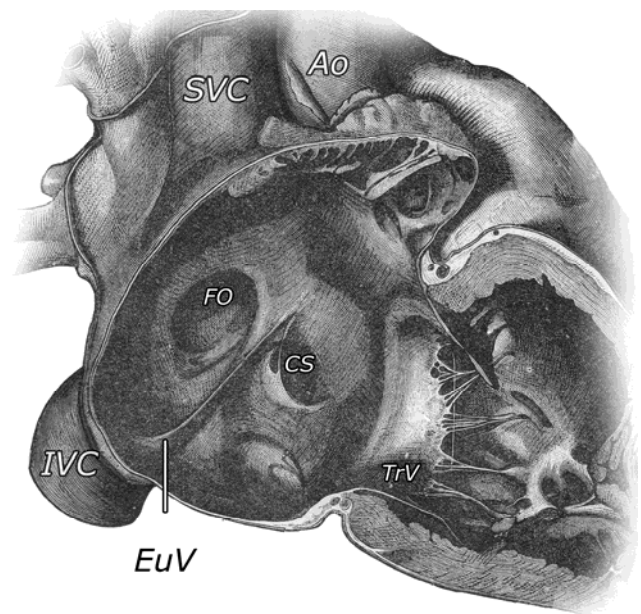


Figure A4. Heart from the right side. The CS ostium is positioned between the tricuspid valve and the IVC. The Eustachian valve/ridge separates the CS ostium from the fossa ovalis. A line drawn between the SVC orifice and the CS ostium—which corresponds with the plane of a modified bicaval view—crosses the fossa ovalis and Eustachian ridge. The absence of any prominence at the inferior edge of the IAS indicates that the “ridge” is minimal at this point along its course. FO = fossa ovalis, EuV = Eustachian valve, TrV = tricuspid valve [From Toldt]

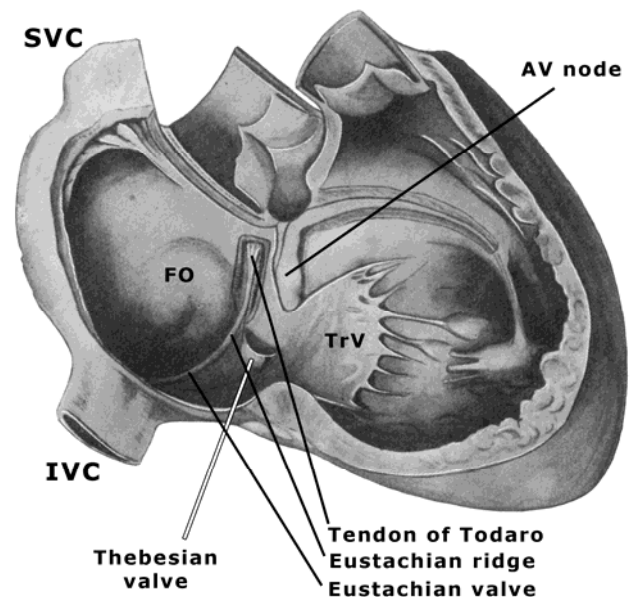


Figure A5. Exposed right heart with the tendon of Todaro and AV node dissected out. The continuum of Eustachian valve—Eustachian ridge—tendon of Todaro is displayed anterior to the IVC and fossa ovalis and posterior to the CS ostium. (The ostium is marked here by the Thebesian valve.) Even in this idealized illustration, the point is made that the tendon of Todaro is subendocardial. Although the tendon is not visible on gross examination, it can be demonstrated as a fold by applying lateral traction on the Eustachian valve. The position of the AV node is also illustrated, under the triangle of Koch. (The triangle of Koch is formed by the CS ostium, tendon of Todaro, and septal leaflet of the tricuspid valve.) FO = fossa ovalis, TrV = tricuspid valve. [From Quain's Anatomy, The Heart by Walmsley]

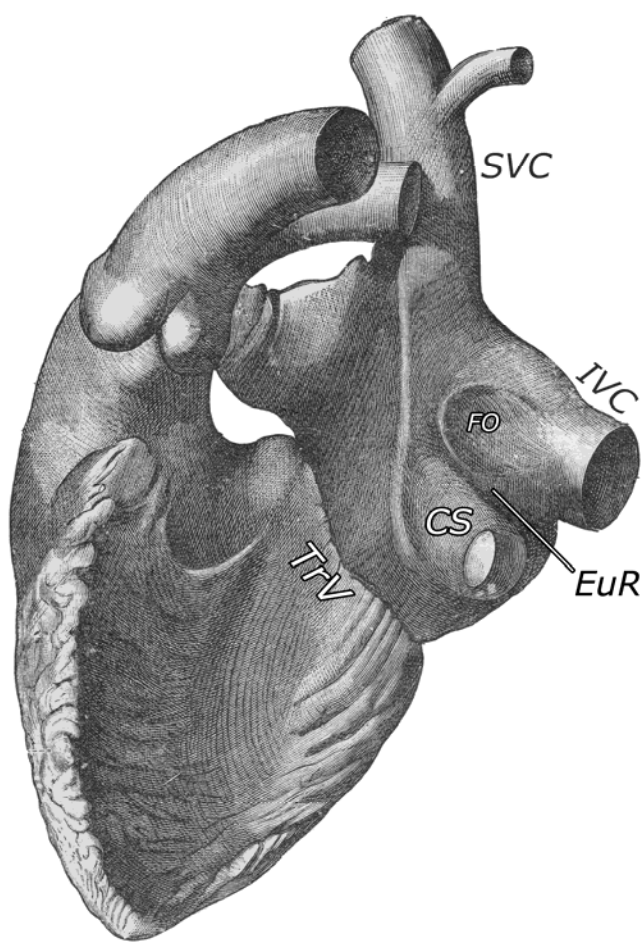


Figure A6. Cast of the right heart. The (roughly) orthogonal relationship between the CS, IVC and tricuspid inlet is illustrated. The IVC and fossa ovalis are separated from the CS by the indentation formed by the Eustachian valve/ridge (EuR). The lightly shaded (vertical) line corresponds with the anterior extent of the interatrial septum, marking the left-anterior boundary of the smooth portion of the RA. [From Toldt]

The anatomy of the right atrium is complex.² However, as a general concept, the major axes of the caval veins, CS, and tricuspid inlet are oriented at nearly right angles to each other [Figures A6 & A7]. The superior vena cava (SVC) and inferior vena cava (IVC) are roughly *perpendicular* to the diaphragm, along a cranial-caudad axis. Both the CS and tricuspid-RV axis are roughly *parallel* to the diaphragm, but at a right angles to each other. The CS is oriented along a left-right axis, while the tricuspid-RV inlets are oriented anterior-posterior. (In actuality, the SVC and IVC are not parallel; the tricuspid-RV axis has a left-inferior component; and the CS axis has a superior-posterior component.)

Coronary Sinus Ostium

The CS ostium is the proximal end of the coronary sinus. A Thebesian valve is present in ~90% of patients, but only covers greater than three-quarters of the ostium in ~20% of normal hearts and ~5% of enlarged hearts.

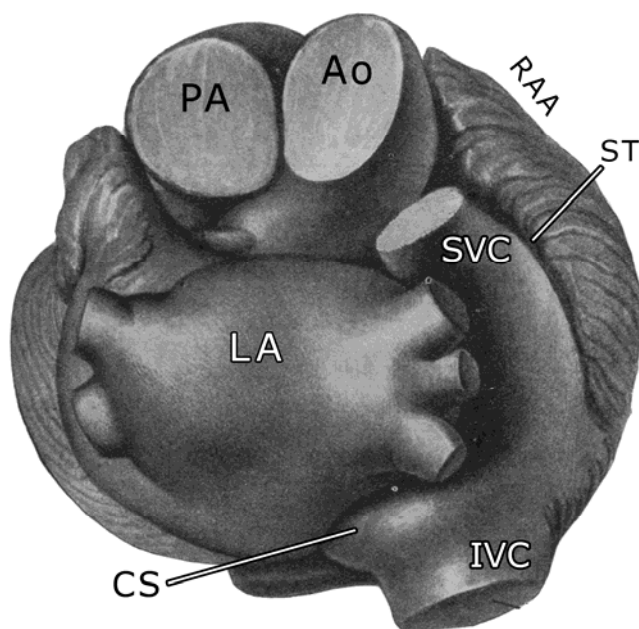


Figure A7. Cast of the right heart, posterior view. The same orthogonal relationships can be seen. The sulcus terminalis (ST)—the boundary between the smooth RA and the RA appendage—extends to the far right and inferior edges of the RA. [From Quain]

The shape of the Thebesian valve has been described as remnant, semilunar, circular,³ and fenestrated.⁴ The ability to display a Thebesian valve with TEE [Figure A8] does not imply difficult catheter engagement.

The position of the CS ostium can be altered by cardiac remodeling, e.g., atrial enlargement. Mitral annular dilation can change the angle of the CS, and asymmetric dilation of the right atrium (common with elevated right atrial pressure) can significantly change the relative location of the CS ostium.⁵ The absolute position of the CS ostium is less important when corrections are based on relative positions, e.g., with TEE-guided catheter manipulation.

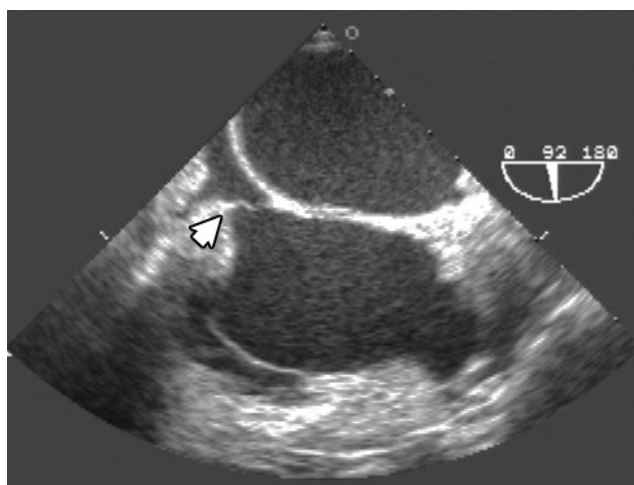


Figure A8. Thebesian valve. A Thebesian valve can be seen at the CS ostium [arrow], but was easily bypassed by the catheter. A middle cardiac vein is visible immediately distal to the valve.

Coronary Sinus

The coronary sinus is located *near* the posterior atrioventricular (AV) groove and is bounded proximally by the CS ostium and distally by the origin of the great cardiac vein. TEE *frequently* reveals the CS to be positioned one or more centimeters above the posterior AV groove, along the inferior wall of the LA [Figure A9].

The transition of the CS into the great cardiac vein is marked by the confluence of the vein of the left atrium (vein of Marshall) or by a valve (of Vieussens), which can often be identified in cadaver specimens by a slight constriction in the CS.⁶ The transition point has little clinical significance and is almost never apparent during catheter advancement or venography. Gray's *Anatomy of the Human Body* lists the length of the CS as 2.25 cm, although more recent studies report a length of 5 ± 0.5 cm.⁶ The average diameter of the CS is ~8 mm (range of 3-15 mm).^{6,7} Calculated volume based on these ranges is ~2.5 ml (range 0.5-8 ml). Although bands and valves can be present as various points along the CS,³ it is unclear how often they impede catheter advancement.

The coronary sinus transmits about three-quarters of the venous drainage of the heart, including almost all of the venous drainage of the left ventricle. Coronary sinus flow is approximately 100-150 ml/min.⁸ Anterior cardiac veins, which empty directly into the RA, drain portions of anterior right ventricle and variable parts of the atria. Thebesian veins also provide venous drainage directly into the associated ventricular chambers, primarily for the right ventricle.⁹

An enlarged CS can be associated with a persistent left superior vena cava (PLSVC) [Figure A10]. This remnant of the embryologic left sinus horn is found in 0.3% of the general population and 3-8% of patients with congenital heart disease. A normal diameter CS does not exclude the possibility of a PLSVC, since a left innominate (brachiocephalic) vein will be present in more than half of patients with a PLSVC.^{9,10} Injection of bubble contrast via a left arm vein can be negative in a patient with a PLSVC if the bulk of left arm venous return is via a bridging brachiocephalic vein.

The CS is dilated in patients with ventricular dilation or poor ventricular function (RV or LV).⁷ Dilation occurs with elevated right atrial (RA) or pulmonary artery (PA) pressure, but has not been found to correlate to the severity of tricuspid regurgitation.¹¹ CS diameter is typically normal in conditions associated with LV hypertrophy, e.g., systemic hypertension, aortic stenosis, and hypertrophic cardiomyopathy.

Coronary sinus shape varies from tubular to funnel-shaped. A subset of patients with supraventricular tachyarrhythmias have an abnormality (windsock CS) where the proximal first centimeter is cylindrically dilated and then tapers distally.^{12,13}

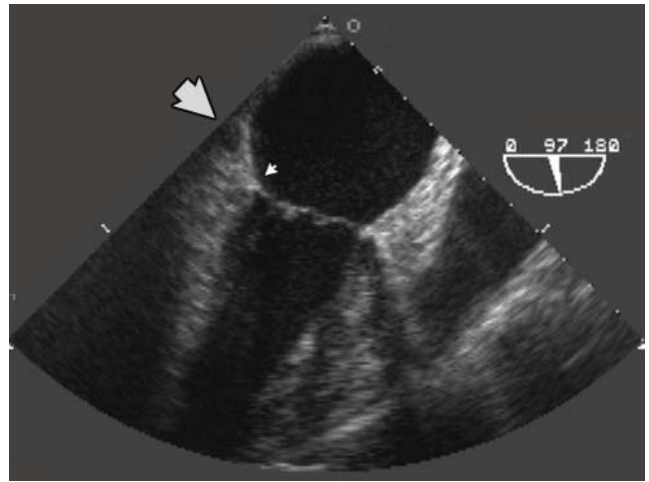


Figure A9. Coronary sinus superior to AV groove. The CS [large arrow] is more than 1 cm above the plane of the posterior AV groove [small arrow]. The projection of the mitral annulus has been described in radiology and anatomy texts—in theory the CS should pass along the inferior border of the annulus. The fluoroscopic projection of the CS in this patient will be slightly superior to what would be expected during PA fluoroscopy.

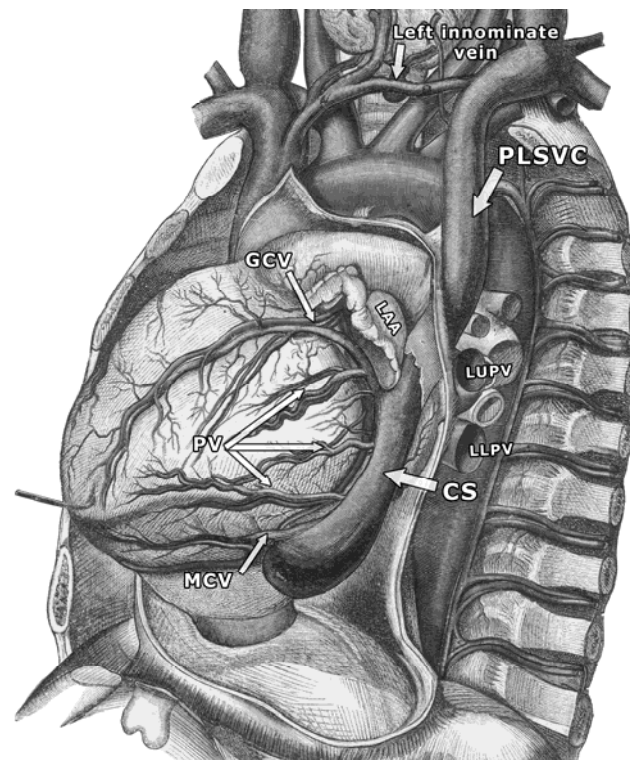


Figure A10. Left persistent SVC, heart viewed from the left with the apex retracted. A large PLSVC passes between the LA appendage (LAA) and the left pulmonary veins (LUPV, LLPV) before it joins the CS. The middle cardiac vein (MCV), posterior ventricular branches (PV), and the great cardiac vein (GCV) are illustrated. In this example a “bridging” left innominate vein is the smaller of the two vessels. The PLSVC follows the same path as the vein of Marshall. [From Toldt]

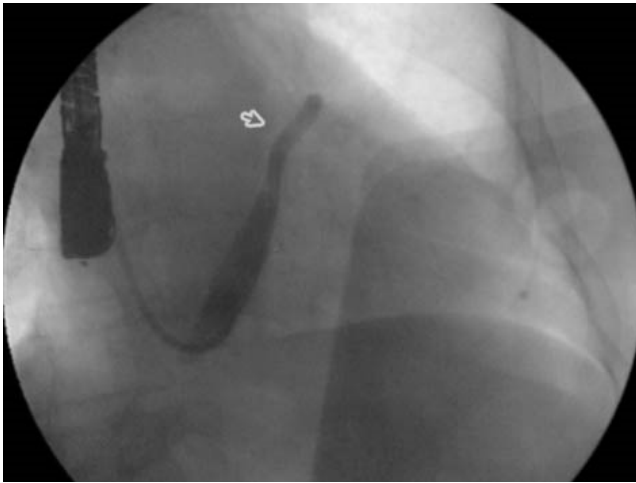


Figure A11. Taper in the mid to distal CS. The CS tapers gradually, beginning about 2 cm from the CS ostium and ending at about 4 cm. The catheter tip [arrow] indicates that the balloon will inflate in a segment with taper. Repositioning the catheter would reduce the likelihood of migration and loss of occlusion.

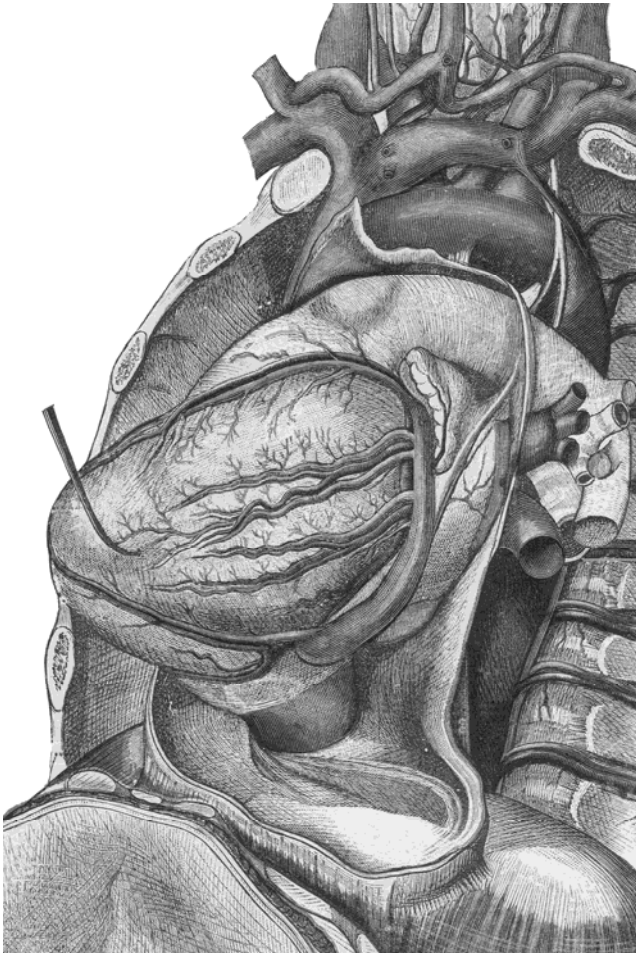


Figure A12. Left surface of the heart, with the apex retracted. The CS and its side branches are entirely within the pericardial space. The pericardial reflection reveals that—with the exception of the CS—the vessels returning blood to the atria are outside the pericardial space. Many of the branches identified in Figure A10 are also visible in this image: posterior ventricular branches, the great cardiac vein, and the middle cardiac vein. The major difference is that the vein of Marshall (VoM) is now in the position previously occupied by the PLSVC. The major axes of the CS, IVC, and tricuspid inlet are roughly perpendicular. [From Toldt]

Almost all coronary sinuses have some degree of taper. Taper is rarely consequential if it is very gradual or if the balloon can be positioned beyond the taper. Positioning the balloon in a tapered segment is analogous to plugging a funnel from wide end. Taper is often confined to the proximal CS, but can extend as far as the great cardiac vein [Figure A11]. Whether from cardioplegia administration, contrast injection, or even normal venous drainage, pressure is always higher on the distal side of the balloon. Balloon migration can be observed during occlusive venography.

The pulmonary and caval veins are situated outside the pericardial space and do not move during the cardiac cycle. In contrast, the CS (and all tributaries) lie within the pericardial space [Figure A12] and move with the surrounding myocardium. Rupture or perforation of the CS or one of its branches can create a hemopericardium.

Coronary Sinus Tributaries

Although there is variability in cardiac venous anatomy,¹⁴ there are predictable CS tributaries [Figure A13]. The *great cardiac vein* (GCV) continues the track of the CS in the AV groove, passing beneath the LA appendage, to then follow the anterior interventricular sulcus. The *middle cardiac vein* (MCV) lies in the posterior interventricular sulcus and joins the CS about 1-2 cm from the CS ostium at an angle of $\sim 90^\circ$.

Between the CS ostium and great cardiac vein there are typically zero to three other branches. One additional side branch is found in 50% of patients, two branches in 45%.^{15,16} The side branch closest to the CS ostium is called a *posterior ventricular* branch, which can join the CS at variable angles and distances from the CS ostium. There can be several posterior ventricular branches. One of the last branches is often called a *left marginal vein*.

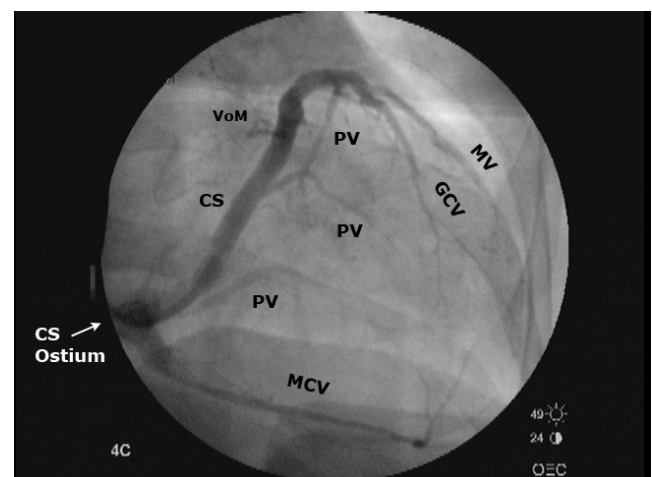


Figure A13. Occlusive venogram. CS tributaries are identified. PV = posterior ventricular branches; GCV = great cardiac vein; MV = marginal vein; MCV = middle cardiac vein; VoM = vein of Marshall (vein of the left atrium).

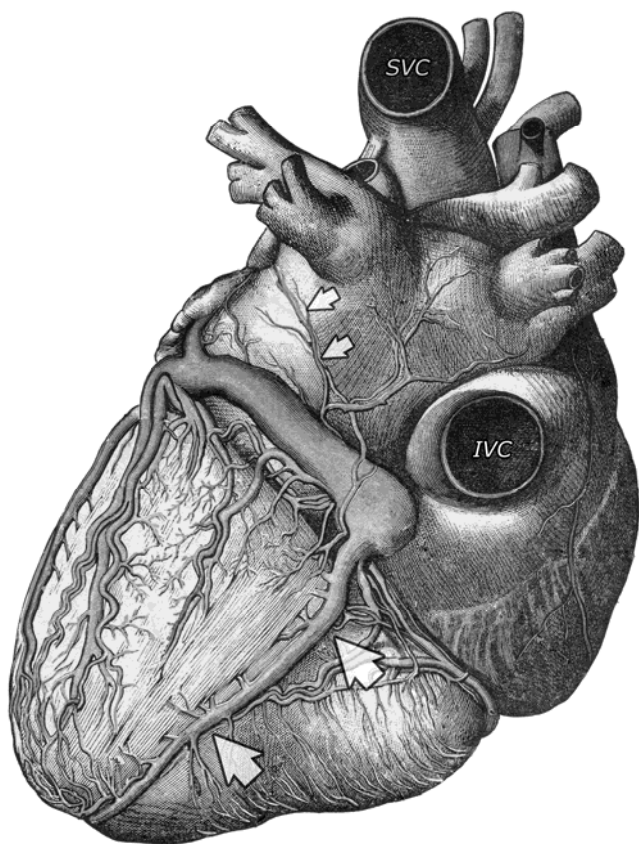


Figure A14. Inferior surface of heart. The middle cardiac vein [large arrows] joins the CS just distal to the CS ostium. The MCV will not be perfused *directly* when the balloon of a cardioplegia catheter is positioned more than ~1 cm beyond the CS ostium. (This is almost always the case, even with a “standard” transatrial cannula.) In most instances the MCV receives retrograde cardioplegia via collateral cardiac veins. The oblique vein of Marshall (small arrows) courses over the posterior LA toward a point posterior (above) the LA appendage. The sulcus terminalis—the external correlate to the crista terminalis—identifies the boundary between the RAA and the smooth portion of the RA, and is seen to the right and below the IVC. [From Toldt]

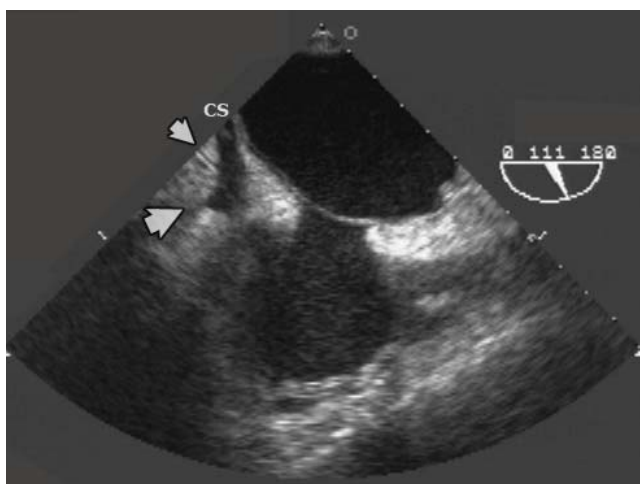


Figure A15. Middle cardiac vein and posterior ventricular branch. The MCV [large arrow] joins the CS about 1 cm from the CS ostium. A PV branch [small arrow] is seen with brightly reflected vessel walls that could be misinterpreted as a misplaced CS catheter. Detection of MCV and PV branches with TEE does not predict difficult catheter placement. Whenever TEE appears to indicate that the catheter has entered a side branch, fluoroscopy remains the best method for diagnosing catheter malposition.

The middle cardiac vein is often seen with TEE in the modified bicaval view [Figure 15]. The MCV can usually be seen (in short axis) by advancing the probe slightly from a deep 4-chamber view, although there is little clinical relevance other than to reveal the proximity of the MCV relative to the CS ostium.

A catheter can enter a posterior ventricular (PV) branch if the alignment is favorable, even when the vessel is not much larger than the catheter [Figure A16]. Occasionally a PV branch will join the RA directly.¹⁷ The appearance of the venogram in this situation has been (incorrectly) described as a “double coronary sinus” [Figure A17]. In this variation, the middle cardiac vein will typically join the PV branch or CS ostium directly.

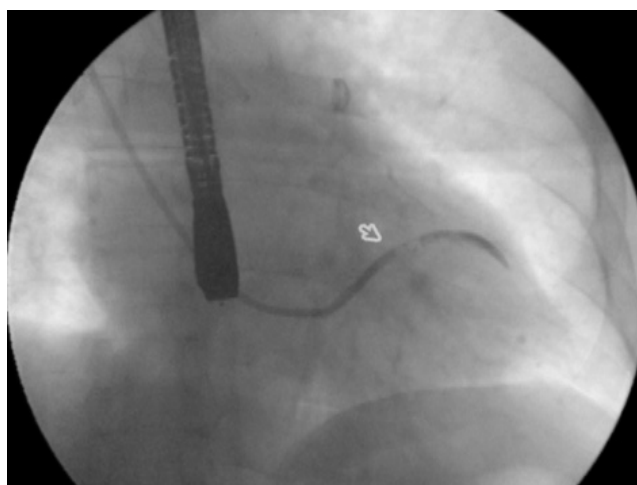


Figure A16. Cannulated small PV branch. The initial concern was that the arc of contrast beyond the catheter tip [arrow] represented extravasation. Complete washout of contrast followed catheter withdrawal into the CS. Occlusive venography after final catheter positioning confirmed that the structure was a PV branch.

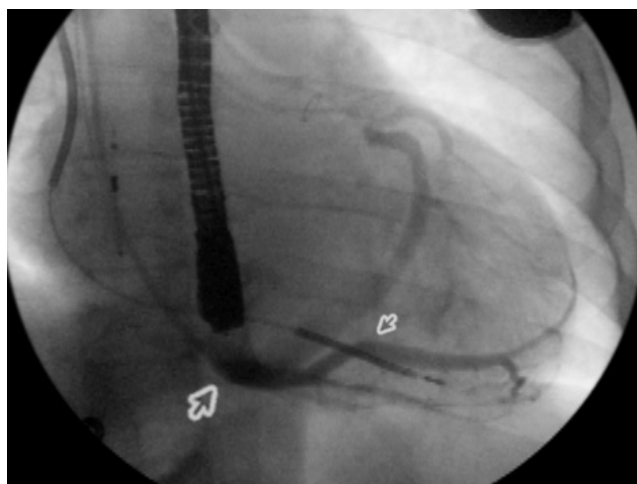


Figure A17. “Double coronary sinus”. The CS (upper vessel) fills by collaterals during a contrast injection from a catheter [small arrow] placed in a shallow PV branch. The PV joins the CS ostium directly [large arrow]. The size of the PV rivals the CS, implying that a substantial watershed of the heart will receive indirect (collateral) perfusion during retrograde cardioplegia. The catheter eventually entered the CS after the shape of the distal curve was modified. Supplemental antegrade cardioplegia was also used.

The vein of Marshall (oblique vein, vein of the LA) is the vestigial remnant of the left anterior cardinal vein (which is also the progenitor of a PLSVC). In contrast to the other CS side branches, the vein of Marshall joins the CS on its superior side [Figure A18]. A catheter will occasionally engage the vein of Marshall [Figure A19].

The great cardiac vein can follow two paths once it reaches the left edge of the posterior AV groove. In 10% of patients it makes a sharp curve as it closely follows the proximal portions of the circumflex and left anterior descending (LAD) coronary arteries.¹⁸ A hairpin turn is seen on fluoroscopy [Figure A17]. In the other 90% the CS follows a “short cut”, resulting in a more gradual curve on fluoroscopy [Figure A18]. (This forms the base of the triangle of Brocq and Mouchet.) Retrograde cardioplegia catheters are typically not placed that deep.

The consistently-present cardiac veins parallel major coronary arteries: the CS parallels the circumflex artery,

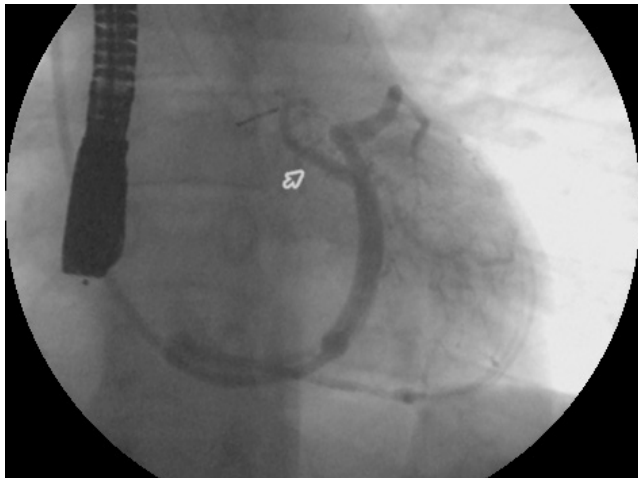


Figure A18. Vein of Marshall with a deep confluence. The arrow identifies the vein of the left atrium. The balloon is the darker circle at the proximal extent of the radiopaque contrast. The vein can join at varying depths from the CS ostium.

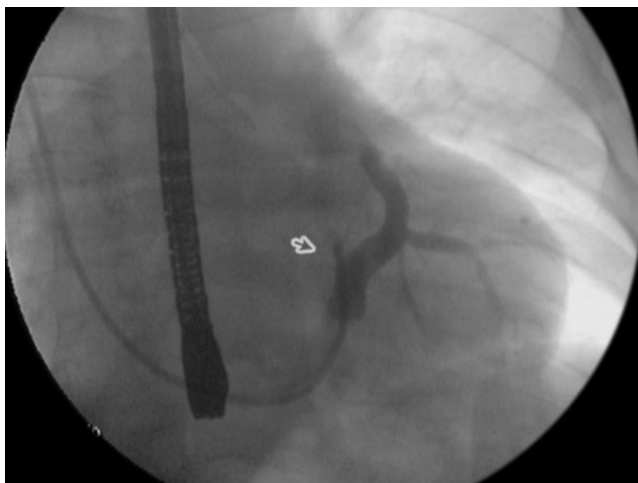


Figure A19. Catheter tip engaging the vein of Marshall. The catheter tip is in the vein of Marshall [arrow], filling sub-millimeter veins with contrast. The catheter tip was repositioned into the CS.

the great cardiac vein parallels the left anterior descending artery, and the middle cardiac vein parallels the posterior descending artery (PDA). The circumflex artery is initially superior to the distal CS, and after passing deep to the CS, is positioned inferior (apically) to the proximal CS. Both the CS and circumflex artery can often be visualized with 2D and CFD TEE [Figure A20].

The CS parallels the posterior segment of the mitral annulus. The average separation is 10 mm, but narrows to 5 mm at the point adjacent to the anterolateral commissure. This is in the region where the CS transitions to become the great cardiac vein.⁶ It is possible for sutures placed near the posterior mitral annulus to involve a CS catheter (or its balloon).

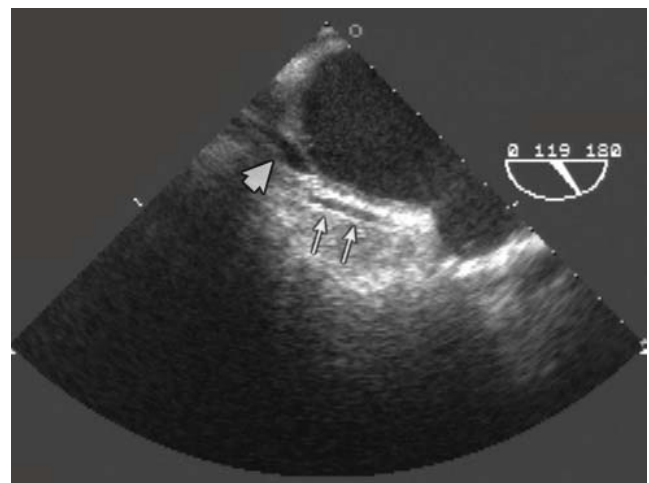


Figure A20. Circumflex coronary artery and great cardiac vein along the left edge of the heart. The circumflex artery [small arrow] and GCV [large arrow] are seen simultaneously in this image. Because the circumflex artery passes deep to the CS, it is encountered first as the probe is turned progressively left. (A slight turn further left in this example displayed a greater length of the CS.) The direction of blood flow in the two vessels is normally parallel, but is opposite during retrograde cardioplegia.

TEE Imaging

Double barrel view equivalents

The Eustachian ridge and valve are TEE landmarks that help confirm the respective identities of the CS and IVC. An ideal “double barrel” view (showing relatively long segments of both the IVC and CS) is not always obtainable. As mentioned in the main article, it is common to only see a short segment of either vessel.

The following images are equally valid in confirming when a suspected structure is the CS. When a modified bicaval view is being sought, the presence of any portion of the IVC in the TEE image suggests that either the probe is turned too far right or that the multiplane angle is too low. The double barrel view has been used to guide catheter manipulation.

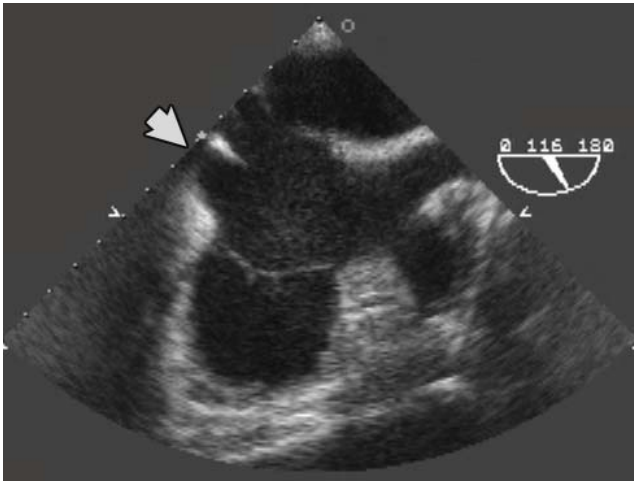


Figure A21. Double barrel view. There are distinct channels in this example. The channel above is the IVC; the one below is the CS [arrow]. If this view is used to guide catheter manipulations, it may display IVC entry, but lacks a septum to “walk” the tip along.

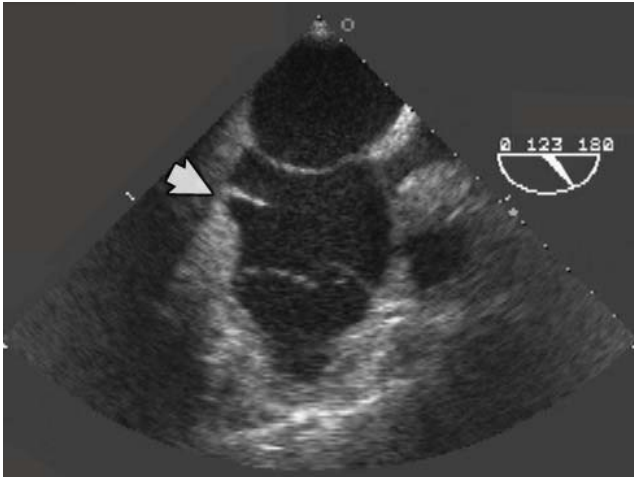


Figure A22. Membranous Eustachian ridge. The thin structure might be more accurately described as a Eustachian valve. The lower channel [arrow] is the CS; the upper is the IVC.

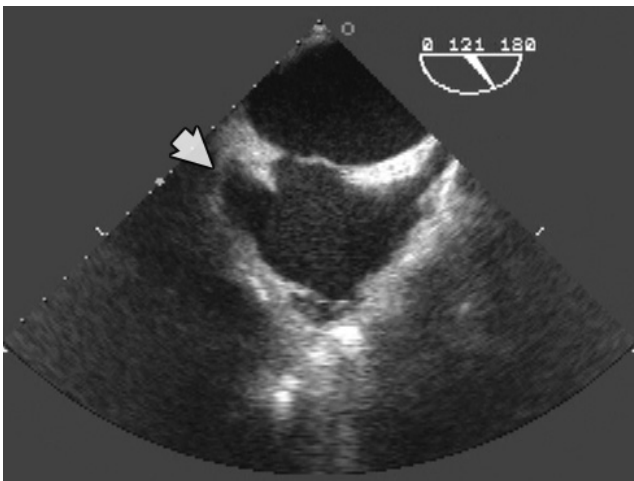


Figure A23. CS with stub IVC. The longer channel below is the CS [arrow]. The pattern of a Eustachian ridge in combination with a short IVC above is a common observation. The projection of the Eustachian ridge can be very subtle at times, akin to the slight protrusion of the blade from a carpenter’s plane.

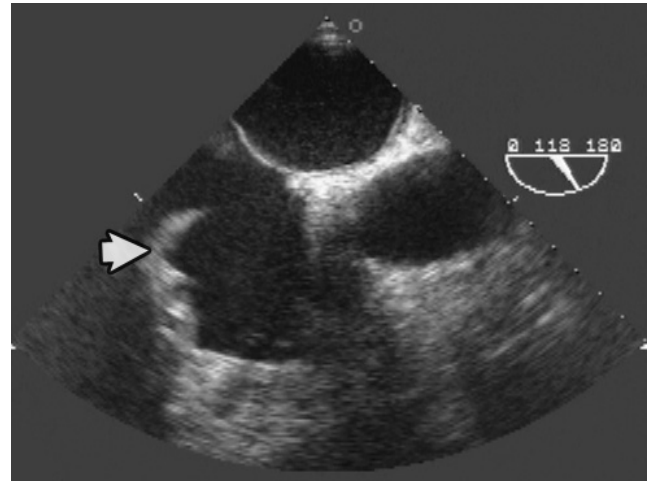


Figure A24. Aortic root and Eustachian “hook”. Turning the probe left will result in the CS appearing in the cove marked by the arrow. Even when a depression is not apparent, the CS will appear in the region below a Eustachian valve as the probe is turned left.

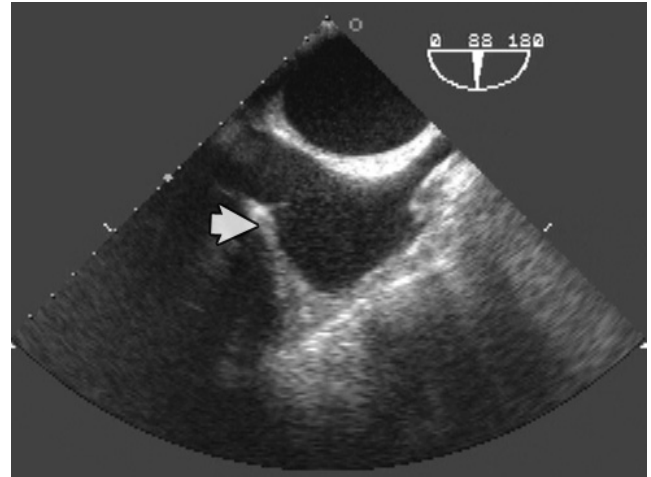


Figure A24. Eustachian valve in a standard bicaval view. The same concept as Figure A23, but at a lower angle. Turning the probe left will result in the CS appearing in the region of the arrow.

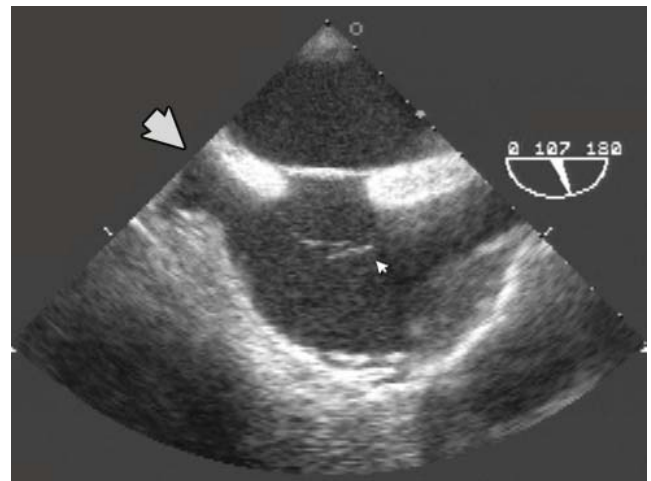


Figure A26. Modified bicaval view with Chiari network. The small arrow points to a Chiari network, which was highly mobile in real-time. The CS [large arrow] is “below” this structure, which originates from the same location as a normal Eustachian valve. The catheter was directed around (below) the network without difficulty. The middle cardiac vein ~1.5 cm distal to the ostium also offers a clue that the target is the CS.

Continuity with a known structure

The identity of the CS can be confirmed in vertical imaging planes by tracking the CS as the probe is turned left or right from a view where the identity of the CS is not in doubt. The most common reference images are a 2-chamber view and a “double barrel” view. (The higher multiplane angle used for a modified bicaval view usually means that turning the probe left will not display a “standard” 2-chamber view, but the primary goal is to view the CS in short axis in the posterior AV groove.) As mentioned in the main article, tracking to or from a 2-chamber view may require simultaneous adjustments in probe depth.

The following five images were obtained by turning the probe progressively left from the starting point of a double barrel view.

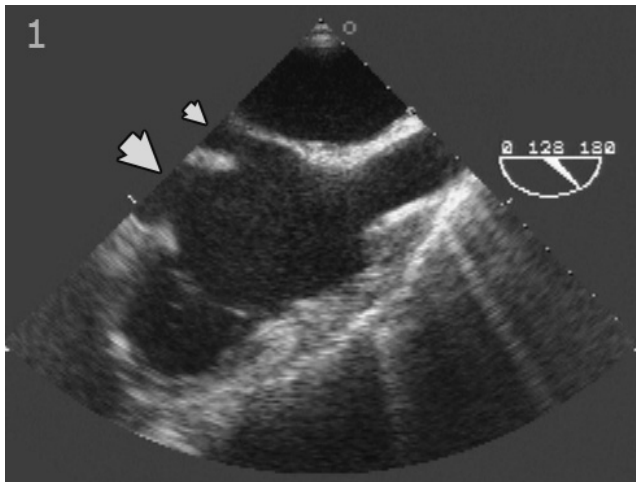


Figure A27. Double barrel view. The CS [large arrow] and IVC [small arrow] are seen at the left edge of the imaging sector. The smaller diameter of the IVC (compared to the CS) results from the off-center intersection of the imaging plane with the IVC.

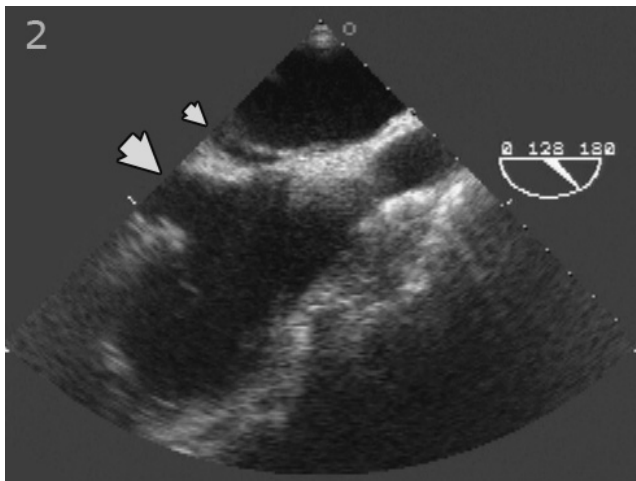


Figure A28. Transition between double barrel and modified bicaval views. The probe has been turned slightly left from Figure A27. The CS is still prominent [large arrow], but the IVC has almost disappeared [small arrow]. The structure that completely separates the IVC and CS is the Eustachian ridge.

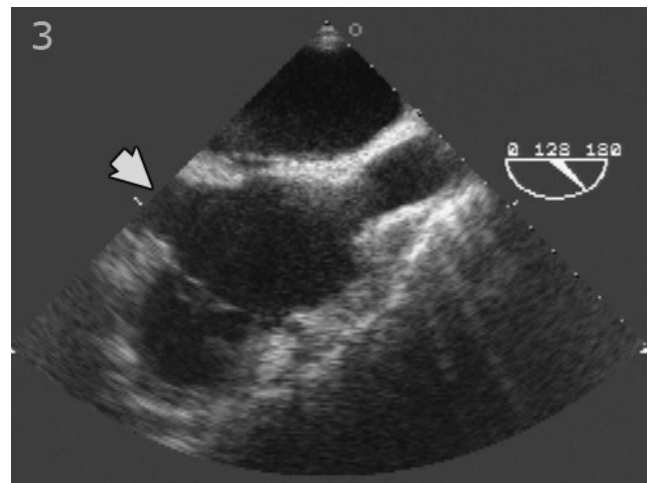


Figure A29. Modified bicaval view. The IVC has disappeared from view as the probe has been turned left from Figure A28. Although the insertion of the tricuspid leaflets is strong evidence that the arrow points to the CS, tracking from a known structure is a more reliable method.

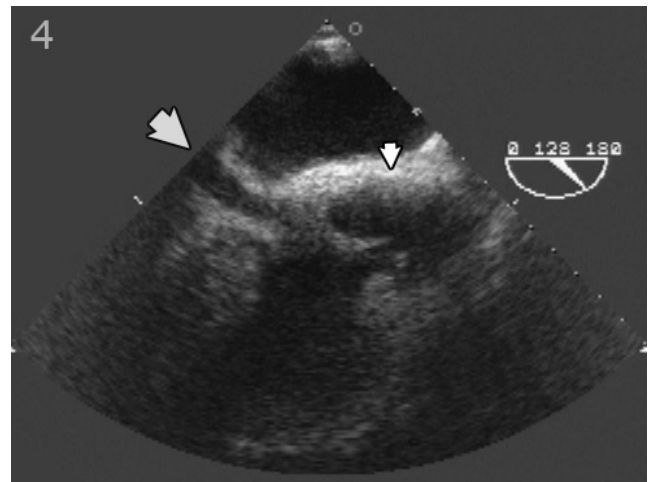


Figure A30. Just left of the modified bicaval view. The probe has been turned left from Figure A29. The proximal CS is seen in long axis [large arrow]. The aortic root is beginning to appear [small arrow].

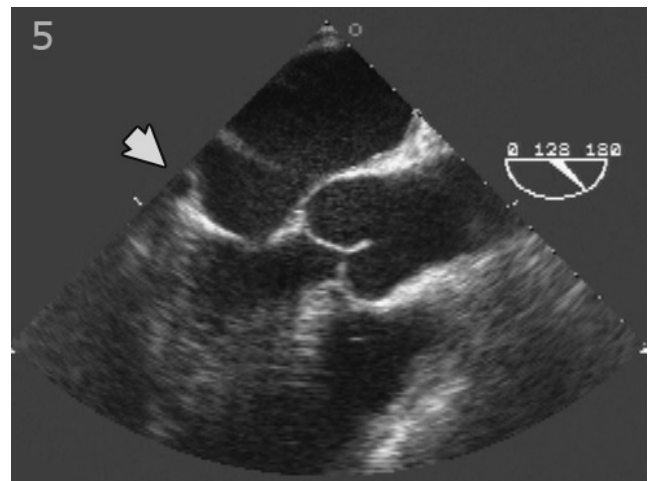


Figure A31. Middle segment of CS in short axis. The final image of the series with the probe turned left from Figure A30. A mid section of CS is seen in short axis [large arrow], similar to its appearance in a 2-chamber view. The aortic root is visible because of the higher multiplane angle.

Variations in the deep 4-chamber view

Even when the deep 4-chamber view is not used to guide engagement of the catheter with the CS ostium, it can offer insights into what to expect in other views. A “double barrel” view can usually be developed when there is a distinct Eustachian *valve* [Figures A32 & A33] or a narrow Eustachian *ridge* [Figure A34]. The double barrel view develops when the TEE imaging plane simultaneously intersects a portion of the IVC and the CS in long axis. (Despite the illusion in the TEE view, the IVC and CS are not parallel. The illusion is similar to the “coumadin ridge” that can often be seen at the junction of the left atrium with the left pulmonary veins.)

It is often difficult to develop a double barrel view when the Eustachian ridge seen in the deep 4-chamber view is indistinct or wide [Figures A35 & A36]. The transition between the IVC and CS in associated vertical TEE planes will usually be subtle in this situation.

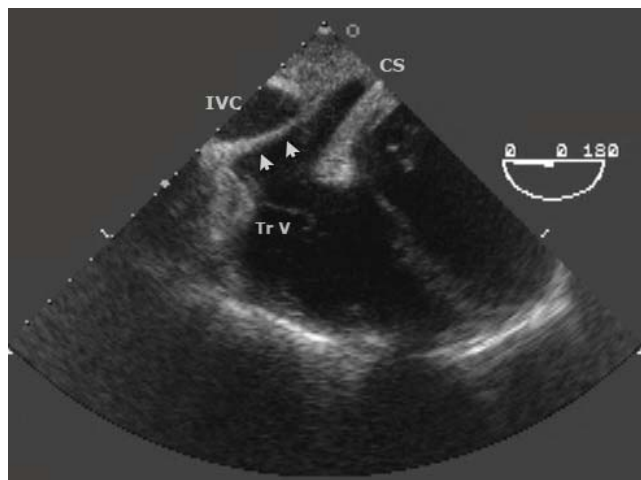


Figure A32. A thin Eustachian valve. The IVC and CS are completely separated by a complete bridge of tissue—a Eustachian valve [arrows]. The CS ostium is in the most inferior portion of the RA (note the small RA and narrow tricuspid inlet).

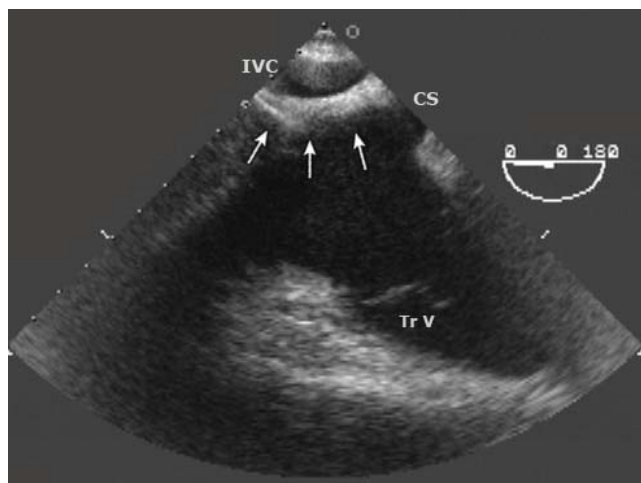


Figure A33. A thick Eustachian valve. Compared to Figure A32 above, there is more RA at the level of the CS. (The Eustachian valve is marked by arrows.)

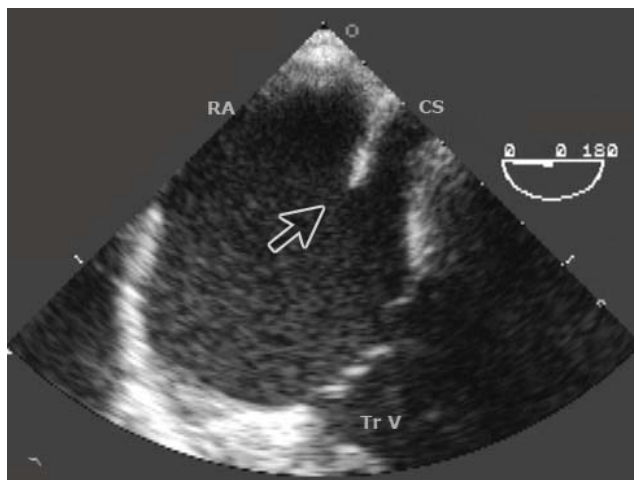


Figure A34. A narrow Eustachian ridge in a deep 4-chamber view. The Eustachian ridge [arrow] divides the lower right atrium and CS. In contrast to Figures A32 and A33, there is incomplete separation of the CS and RA/IVC. A distinct “double barrel” view was obtained easily in this patient.

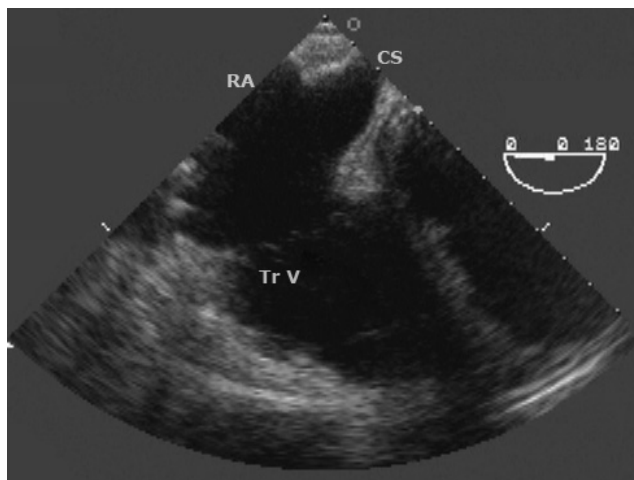


Figure A35. Deep 4-chamber view with indistinct Eustachian ridge. The proximal CS has moderate taper. As the probe was turned right from a modified bicaval view, there was no distinct transition as the IVC began to appear in the view.

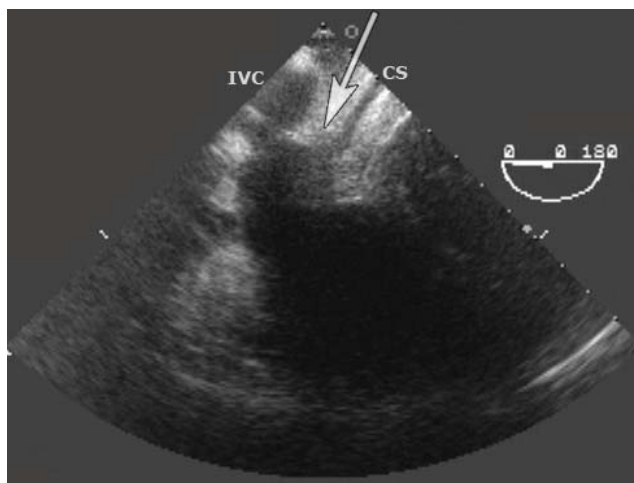


Figure A36. Deep 4-chamber with wide Eustachian ridge. The arrow identifies the Eustachian ridge. Despite the small caliber of the CS, cannulation was successful.

Exceptions to the “tricuspid leaflet landmark”

One of the most easily obtained TEE landmarks for identifying the CS ostium is the insertion of tricuspid leaflets next to the CS ostium. This landmark offers several advantages. At the multiplane angles used for the modified bicaval view, tricuspid leaflets can be acquired in 100% of patients. The CS is usually a very small turn to the right from the tricuspid valve, without any need to change probe depth. The “CS in the middle” relationship makes it a near-certainty that the imaging plane will intersect the CS before it intersects the IVC.

Every rule has an exception, however, and tricuspid leaflets can *very rarely* be observed inserting near the IVC orifice. In author’s observed exceptions, turning the probe further left *also* showed tricuspid leaflets inserting next to the ostium of the smaller diameter CS. A better rule in these cases might have been that the CS is the first channel to the right of the tricuspid leaflets.

Mistaking the IVC for the CS usually has minimal practical consequences. Little time is consumed between the *intentional* insertion of the catheter into the IVC and its discovery with fluoroscopy. It arguably consumes less time to insert the catheter into a *plausible* target than what might be spent struggling with a TEE view. Knowledge of the potential to confuse the IVC and CS facilitates a rapid transition to backup techniques or to a search for other TEE landmarks.

The images on this page [Figures A37, A38, A39 & A40] illustrate one example of an “exception to the rule”. The finding was noted in passing, since the true modified bicaval view was easily acquired with a small turn of the probe to the left. Catheter placement proceeded without any positioning errors.

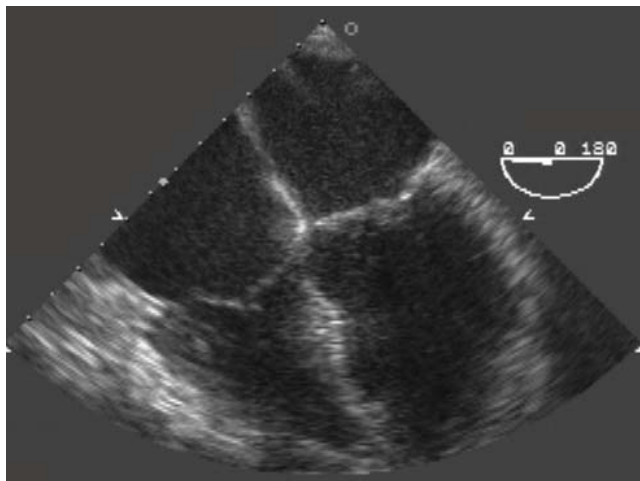


Figure A37. Standard 4-chamber view. The patient had chronic mitral regurgitation and severe biatrial enlargement. Significant cardiac remodeling raises the possibility that the normal orientations of the tricuspid valve, CS, and IVC will be altered.

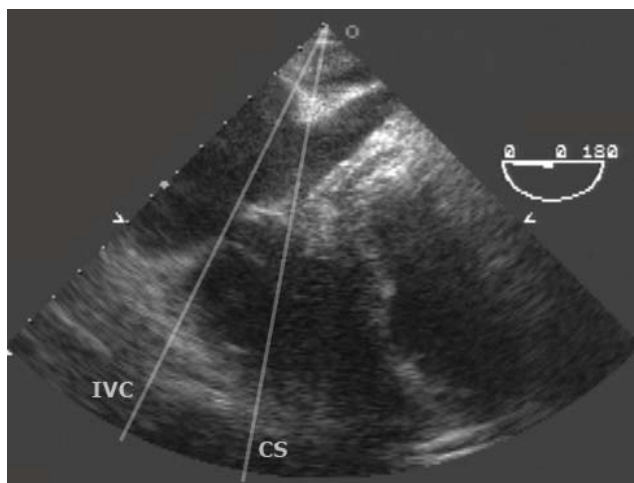


Figure A38. Deep 4-chamber view. The indistinct Eustachian ridge suggests that the possibility of a subtle transition between the CS and IVC. The lines represent orthogonal imaging planes that intersect the CS ostium and IVC respectively. Tricuspid leaflets are intersected by both lines, suggesting that vertical imaging planes through the tricuspid valve could also intersect *either* the CS or IVC.

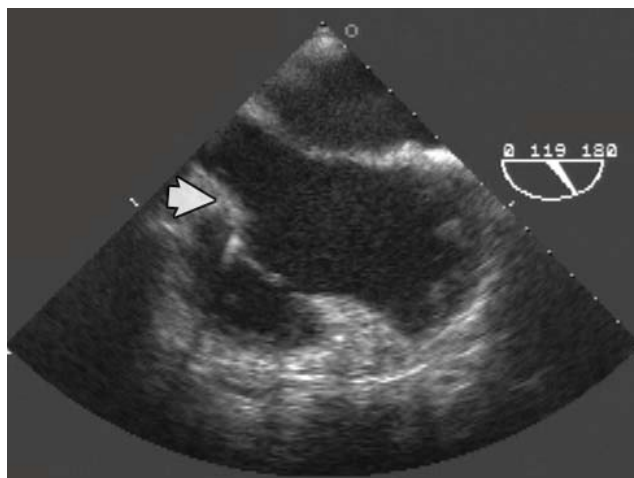


Figure A39. Tricuspid leaflets inserting at the IVC orifice. The IVC diameter is ~20 mm. (Leaflet insertion is at the arrow.)

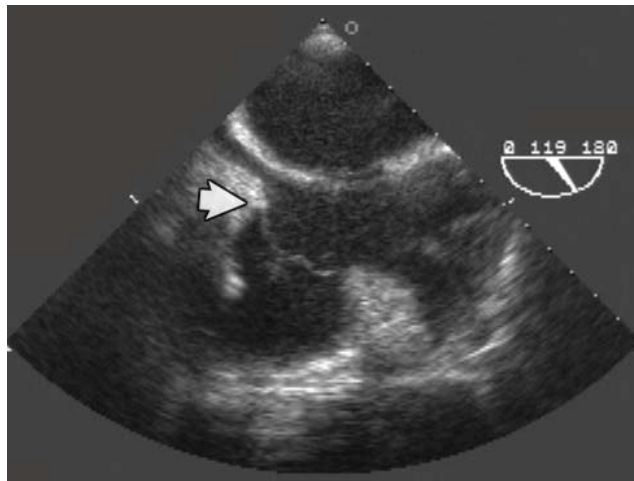


Figure A40. Modified bicaval view. The normal relationship of tricuspid leaflet insertion is seen [arrow]. A small turn of the probe left from Figure A39 developed this view, primarily as an abrupt change in vessel diameter.

Sample screening TEE exam

The full TEE exam is sometimes deferred until after catheter placement. A screening TEE exam should precede catheter placement. The following screening exam is suitable for many minimally invasive cardiac operations. The general order is 4-chamber, transgastric views, thoracic aorta, and lastly vertical imaging planes.

1. Standard 4-chamber [general overview, MR, TR]
2. Deep 4-chamber [proximal CS]
3. Transgastric short axis [LV and RV]
4. Short axis descending aorta [aortic screening]
5. Short axis transverse aorta [aortic screening]
6. ME 2-chamber [LAA, LV, CS in short axis]
7. ME long axis [aortic root, screen for MR, AI]
8. Modified bicaval [preview catheter path]

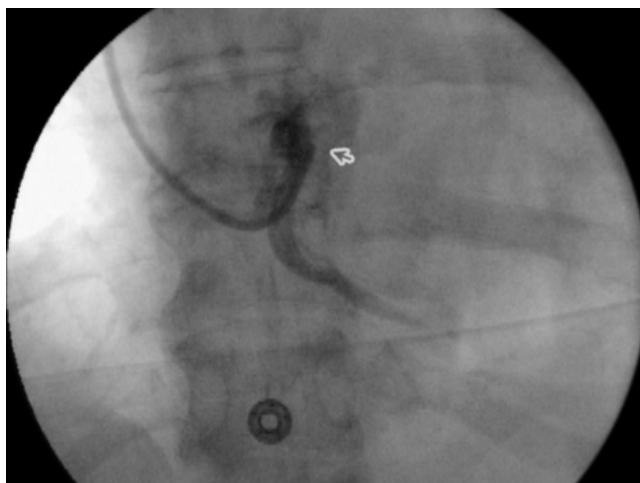


Figure A41. Catheter engaged in middle cardiac vein orifice. The catheter was impeded by engagement of the MCV ostium. The apical track of contrast identifies the vessel. The pattern should not be interpreted as dissection. The wisps of contrast represent the mixing of contrast and RA blood.

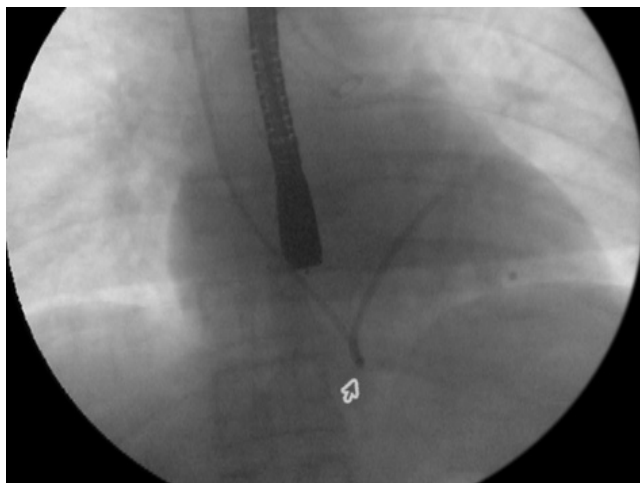


Figure A42. Twisting catheter. The arrow marks the point where the catheter appears to fold over on itself. The catheter is forming an acute bow near the CS ostium that is aligned with the fluoroscopic projection. The catheter in this example is already a substantial distance beyond the CS ostium. The force involved in producing this twist contributes little to catheter advancement and risks vessel injury.

TEE miscellany

Every TEE display has a depth setting where the displayed images are life size, i.e., centimeter depth marks on the display are *physically* separated by 1 cm. Displaying structures at “life size” may be instructive in visualizing catheter paths and/or curves. Freezing a “life size” image of the modified bicaval view allows the opportunity to overlay a stylet (or other malleable object) along the ideal path between the SVC and CS. This provides a tangible representation that may be of value if the catheter needs to be reshaped.

Fluoroscopy

Occlusive venography consistently displays all major side branches, even those proximal to the point of balloon occlusion. Despite the variability in cardiac venous anatomy, venous drainage of the heart forms a plexus with numerous communications.¹⁹ However, laboratory studies suggest that retrograde cardioplegia may not perfuse the free wall of the RV and/or portions of the interventricular septum as well as the rest of the LV, even when delivered optimally.⁹ Antegrade cardioplegia should supplement retrograde cardioplegia when dictated by clinical circumstances.

Pattern recognition is a large component of applied imaging. Two useful patterns are noted [Figures A41 & A42]. While patterns are helpful, variations in anatomy can lead to incorrect assumptions. Contrast injection is very effective in clarifying uncertain (or unexpected) catheter tracking. Small injections of contrast are highly recommended when catheter advancement appears to be impeded.

Other Considerations

Monitoring ergonomics

“Slave” monitors can be used to group imaging and pressure information within a small viewing arc. A dedicated video cart is often used to group monitors. Modern TEE and fluoroscopy platforms have “video out” capability.

Practice and review

Practice of TEE views can be performed on patients undergoing all types of cardiac surgery. Anesthesia administration during electrophysiologic procedures, e.g. ablations or placement of leads for biventricular pacing, allows an opportunity to expand familiarity with cardiac fluoroscopy.

Most modern TEE systems archive information as digital loops. While this method works well for documenting stable, reproducible conditions, it is suboptimal for capturing the fleeting, unpredictable events that can occur during CS catheter placement. One challenge is dealing with the file size generated by the capture of extended periods of video data. One approach is to use a digital video camera (as a VCR) to record catheter placement for later review. Video switch boxes can be used to allow easy capture of TEE and fluoroscopy imaging with a single recorder.

Troubleshooting possible catheter dislodgment

If a catheter becomes dislodged by the IVC cannula, reinsertion *can* be attempted, although it will be difficult if the IVC cannula is in place. Reintroducing fluoroscopy may be difficult at this point, and the decision to attempt replacement may be dictated by the feasibility of resorting to antegrade administration as the sole method for cardioplegia.

If there is a concern that the CS catheter may have been dislodged, the presence of multiple catheters in the right atrium can make it difficult to answer the question with standard TEE imaging. It can be difficult to display the catheter with TEE even when it is known to be in the CS, since the catheter can move the catheter out of the expected imaging plane as it advances in the CS. Injection of a small amount of agitated saline—0.5 ml is usually sufficient—should reveal bubble contrast emerging from the CS. Blood gas analysis of a slowly aspirated specimen should also confirm position. However, neither of the latter two will indicate catheter depth.

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