Percutaneous Trans-Hepatic Venous Access for Catheter Ablation Procedures in Patients with Interruption of the Inferior Vena Cava

Running title: Singh et al.; Trans-hepatic venous access

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Abstract:

**Background**—Catheter ablation of left-sided atrial arrhythmias is generally performed using a transfemoral venous approach, through the inferior vena cava (IVC). This article assessed the feasibility of a percutaneous transhepatic approach to ablation of left-sided atrial arrhythmias in two patients with interruption of the IVC.

**Methods and Results**—Patient #1 had atrial flutter in the setting of complex congenital heart disease, and prior Fontan for univentricular physiology and a single atrium. Patient #2 had atrial fibrillation. Percutaneous hepatic vein access was obtained with ultrasound and fluoroscopic guidance. Transseptal catheterization was performed in Patient #2. After the procedure, the hepatic tract in Patient #1 was cauterized using a bipolar radiofrequency catheter, and an Amplatzer vascular plug used in Patient #2 to obtain hemostasis. Percutaneous hepatic vein access was achieved without complications. After electroanatomical mapping, a linear lesion was placed between the single atrioventricular (AV) valve and the confluence of the hepatic veins in Patient #1; this terminated the flutter and bidirectional block was achieved. In Patient #2, the pulmonary veins (PVs) were electrically isolated using an extra-ostial approach isolating the ipsilateral veins in pairs. Also, ablation of right atrial flutter was achieved by obtaining bidirectional block across a linear lesion between the tricuspid valve and confluence of the hepatic veins. Hemostasis of the transhepatic tract was attained in both patients.

**Conclusions**—In patients with interrupted IVCs, a percutaneous transhepatic approach is a feasible alternative for performing catheter ablation of complex left-sided arrhythmias.

**Key Words:** congenital heart disease; atrial flutter; atrial fibrillation; ablation; hepatic vein
**Abbreviations:**

ACT = activated clotting time

AV = atrio-ventricular

CS = coronary sinus

Fr = French

GA = gauge

INR = international normalized ratio

IJ = internal jugular

IVC = inferior vena cava

LA = left atrium

LV = left ventricle

PV = pulmonary vein

RA = right atrium

SVC = superior vena cava
The success of catheter ablation for the treatment of cardiac arrhythmias has expanded the patient population eligible to receive this therapy. While catheter positioning is typically achieved via the femoral veins, there are patients in whom this approach is not possible due to venous occlusion or absence of the inferior vena cava (IVC; Figure 1). In these rare situations, access to the heart may still be achieved with a superior approach; that is, with catheters descending from the superior vena cava (SVC) into the right heart (1-9). Alternatively, left-heart arrhythmias may be accessed using a retrograde aortic approach (10). However, these approaches are less favorable due to diminished catheter control and stability.

The percutaneous trans-hepatic approach is an alternative method of obtaining venous access when traditional means are not possible, and can provide access to the heart from an inferior approach (11-19). This approach has been reported to be feasible with a complication rate of less than five percent (20). While this approach has most frequently been described in children undergoing invasive electrophysiology procedures (21-24), there are no such reports of its use in adults. In this manuscript, we describe two patients with congenitally interrupted IVCs in whom the percutaneous trans-hepatic approach was successfully employed to eliminate atrial arrhythmias.

Methods and Results:

Percutaneous catheter ablation was performed in two patients with interruption of the IVC. The approach and considerations for obtaining hepatic venous access as well as achieving hemostasis upon completion of the procedure is described in detail for each patient.
Case 1:

A 36-year old female with a history of complex congenital heart disease and prior Fontan procedure, had a 10 year history of symptomatic atrial flutter resistant to Beta-Blockers, Digoxin, Sotalol and Amiodarone (Figure 2A). She was born with i) a single ventricle, ii) a single atrium with pulmonary and hepatic veins but complete absence of the IVC, iii) a persistent left SVC, iv) a single atrio-ventricular (AV) valve, and v) D-transposition of the great vessels. At the age of 3, she underwent a palliative subclavian to pulmonary artery anastomosis. And at the age of 28, she underwent i) a Fontan procedure with a total cavo-pulmonary connection in Kawashima modification (pulmonary truck disconnection, anastomosis of the left SVC and azygous veins to the left pulmonary artery, ii) placement of a Carpentier AV ring, and iii) placement of an epicardial DDD permanent pacemaker.

She was brought to the electrophysiology laboratory to undergo catheter ablation of atrial flutter. Pre-procedural CT imaging demonstrated the absence of an IVC and confirmed drainage of the hepatic veins directly into the single atrium (Figure 1B, 1C, 2B). Initially, an attempt to access the single atrium using a retrograde aortic approach was unsuccessful – likely because of the Carpentier AV ring. Accordingly, access to the single atrium was planned via a transhepatic approach.

The procedure was performed with conscious sedation. The INR the morning of the procedure was 1.0. Femoral venous access was obtained and a quadripolar catheter placed in the azygous vein posterior to the single atrium; the far-field atrial electrogram served as a timing reference. The right upper abdomen was prepped and draped in a
sterile fashion. Percutaneous trans-hepatic access was then obtained using a 22 GA Chiba needle (EMcision Ltd, London, UK) placed below the right costal margin between the mid-clavicular and right anterior axillary line. The position and trajectory of the needle was guided by visualization of the hepatic vein with ultrasound (Figure 3A). The needle was advanced with intermittent aspiration and injection of contrast to document entry into the hepatic vein (Figure 3B, 3C, Supplemental online video 1). Once the vein was entered, a guidewire was placed into the single atrium and the needle exchanged for a standard 8Fr vascular sheath (Supplemental online video 2). At this point, intravenous heparin was administered to achieve an ACT > 300 seconds.

The procedure was performed using the Navistar RMT Thermocool catheter (Biosense Webster, Diamond Bar, CA) guided by the Niobe II magnetic navigation system (Stereotaxis, St. Louis, MO). Initially, the 3-dimensional rendering of the cardiac anatomy was rapidly integrated with the electroanatomical mapping system (CARTO, Biosense Webster) by mapping the arch and descending aorta (Figure 2B, Supplemental online video 3). Using a combination of activation and entrainment mapping, the atrial flutter was identified to be a macro-reentrant circuit coursing around the AV annulus (Figure 2B, Supplemental online video 4). Importantly, the circuit was demonstrated to traverse through the isthmus between this single AV valve and the confluence of the hepatic veins as they enter the atrium. Accordingly, radiofrequency energy was delivered to create a linear lesion between the AV valve and the hepatic venous confluence (Figure 2B). Termination of the arrhythmia occurred during ablation and the arrhythmia remained non-inducible. Also, isthmus block was demonstrated with differential pacing maneuvers utilizing a duo-decapolar catheter placed within the single atrium (see Figure
The overall procedure time was 230 minutes, and required 15 minutes of fluoroscopy.

At the end of the procedure, Protamine was administered to reverse the heparin. The hepatic sheath was withdrawn from the lumen of the hepatic vein and positioned within the liver parenchyma just outside the site where the hepatic vein was entered (confirmed by contrast injection). A commercially available 5 Fr endovascular bipolar radiofrequency catheter commonly used for vascular occlusion (EMcision Ltd, London, UK) was placed through this sheath into the hepatic tract (Figure 4A). Bipolar radiofrequency energy was applied (20 Watts) within the hepatic tract – thereby coagulating the adjacent hepatic tissue to achieve immediate hemostasis. No peri-procedural complications occurred. Full anticoagulation with intravenous Heparin and Warfarin therapy was initiated 6 hours post-procedure. The patient has had no recurrence of arrhythmias in the subsequent 18 months of follow-up.

Case 2:

A 58-year old female with a history of an aortic arch aneurysm with a Bentall procedure in 1976, had symptomatic drug-refractory paroxysmal atrial fibrillation. Because of severe depression of her left ventricular (LV) ejection fraction (28%) thought to be resulting from tachycardiomyopathy, she was scheduled to undergo a catheter ablation procedure. A pre-procedure CT scan revealed the presence of a left sided SVC and a dilated hemi-azygous vein, the latter of which was highly suggestive of the absence of an IVC.
The INR the morning of the procedure was 1.7. The procedure was performed under general anesthesia. Femoral venous access was obtained and a decapolar catheter advanced through the right femoral vein. The catheter coursed to the left of the spinal column through an azygous vein, and then entered the right atrium (RA) through the persistent left SVC and coronary sinus (Figure 5A, Supplemental online video 5); the IVC was confirmed to be absent. Right internal jugular (IJ) venous access was then obtained and a second decapolar catheter was placed through the RA into a hepatic vein (Figure 5A, Supplemental online video 5).

Percutaneous hepatic venous access was obtained using a seven inch 22GA spinal needle (BD Medical, Franklin Lakes, NJ) under fluoroscopic and ultrasound guidance. Entry was obtained below the right costal margin between the mid clavicular and right anterior axillary line. The trajectory of the needle was similar to the angle required for the ultrasound transducer probe to visualize a hepatic vein. Additionally, a trans-esophageal echocardiogram probe was placed in the stomach which also allowed for visualization of the needle and the hepatic vein. The decapolar catheter in the hepatic vein also served as a fluoroscopic guide to help direct the needle in the appropriate direction (Figure 5A, 5B, Supplemental online video 5). The needle was advanced with intermittent aspiration and contrast injection to determine when the vein was entered (Figure 5A, 5B, Supplemental online video 5).

Once the vein was entered an angioplasty guidewire was inserted through the needle and advanced into the RA (Figure 5B, Supplemental online video 5). The needle was then exchanged and serial dilation performed with a 6 and 8Fr dilator. Then, the angioplasty guidewire was exchanged for a 0.035 inch guidewire (Figure 5C,
Supplemental online video 5) and an SL1 sheath subsequently placed in the RA. A 10,000 unit heparin bolus was administered prior to performing transseptal puncture, and a heparin infusion initiated to maintain an ACT > 300 seconds. To minimize peri-procedural complications, a single transseptal puncture was performed using fluoroscopic and transesophageal echocardiogram guidance. Because of difficulty crossing the inter-atrial septum, radiofrequency energy (20 Watts) was delivered to the hub of the transseptal needle to facilitate perforation. Once the SL1 was placed within the left atrium (LA), it was exchanged over a guidewire for a deflectable sheath (Agilis, St Jude Medical, Inc.; see Figure 5, Supplemental online video 5).

An electroanatomical mapping system (NavX, St Jude Medical, Minneapolis MN) and a multispline catheter (Pentaray, Biosense Webster) were employed to create 3-dimensional geometric renderings of the various chambers of the heart (LA-pulmonary veins (PVs), RA, CS and left-sided SVC) (Figure 6A, 6B, Supplemental online video 6). The multispline catheter was employed because i) in addition to its ability to rapidly created geometry and collect electrical information, ii) its ability to conform to anatomy was particularly relevant in this patient whose antero-posterior left atrial dimension was particularly small. As shown in Figure 6A, 6B, and the Supplemental online video 6, this patient has a quite flattened LA anatomy, and based on our prior experience with other patients with this anomalous atrial geometry, we felt that the multispline catheter would be easier to use than a standard circular mapping catheter.

Using an externally-irrigated radiofrequency ablation catheter (Celsius Thermocool catheter, Biosense Webster Inc.), lesions were placed in the peri-ostial region to electrically isolate the PVs in ipsilateral pairs (Figure 6A, 6B). PV isolation
was confirmed with the multispline catheter. In addition, there was complete absence of pace-capture (10mV, 2 msec) on the ablation line (25). Additionally, in the right atrium, a linear lesion was placed in the isthmus region between the tricuspid annulus and confluence of the hepatic veins into the right atrium (Figure 6A, 6B). Bidirectional block was confirmed by differential pacing from the ostium of the coronary sinus and measuring the conduction time to two locations on the lateral right atrium and vice versa. Finally, ablation lesions were placed at the left-sided SVC. The overall procedure time was 330 minutes, and required approximately 35 minutes of fluoroscopy.

At the end of the procedure, Protamine was given to reverse the Heparin. The transseptal sheath was exchanged for a short 8Fr vascular sheath whose tip was positioned within the hepatic vein (Figure 4B, Supplemental online video 5). The vascular sheath was then withdrawn such that the tip was situated just outside of the hepatic vein lumen. An Amplatzer Vascular Plug (AGA Medical, Plymouth, MN) was placed within the lumen of the hepatic tract to achieve hemostasis (Figure 4C, 4D, Supplemental online video 5). In addition, Gel Foam sponge (Pfizer, New York, NY) was also placed though the vascular sheath into the tract. No peri-procedural complications occurred and Warfarin therapy was maintained throughout the peri-procedural period. No arrhythmias were detected during the follow-up period (4 months), and the repeat LV ejection fraction at 3 months post-procedure had improved to a near-normal level (45%).

Discussion:
Congenital abnormalities of the venous system are rare but well-described with interruption or congenital stenosis of the IVC occurring in approximately 0.15% of the general population (26). In the most common variant of IVC interruption, the segment of the IVC between the hepatic and renal veins is absent, with blood from the liver typically draining directly into the RA via hepatic veins and that from the lower extremities draining into the RA via the azygous system (Figure 1A). Knowledge of this anatomic variation is vital as it allows invasive electrophysiologists to thoughtfully plan a percutaneous approach.

Alternative approaches of entry to the atria are possible when the IVC is not available. A superior approach via the SVC has been well described for invasive electrophysiology procedures including atrial flutter and fibrillation procedures (1-9). However this approach may be suboptimal for both of the above described procedures. Variation in respiration may prevent optimal tissue-catheter contact during RA isthmus ablation (1). Transseptal access may also be challenging with a superior approach due to the lack of sheath support when positioning and puncturing through the fossa ovalis. Additionally, the lack of support from the lower rim of the fossa ovalis may increase the difficulty of performing ablation adjacent to the left inferior pulmonary vein (8), and the tight curve required to ablate the right pulmonary veins also increases the difficulty of ablation in the antrum of the right pulmonary veins (9). In rare circumstances with IVC interruption, suprarenal branching may be present with an IVC remnant draining into the hepatic veins which subsequently drain into the RA (27). In this situation, one may access the RA with an inferior approach passing the long transseptal sheath through this anomalous venous system. However, this situation is exceptionally rare.
Another alternative is the retrograde aortic approach (10). However, this approach was not employed in either of our patients because i) the technical difficulty in placing the catheter across the Carpentier AV ring in patient #1, and ii) the technical difficulty of placing continuous linear lesions to permanently isolate the PVs in patient #2. Of note, the LA-PV geometry was particularly challenging in patient #2 because of the minimal antero-posterior left atrial dimension (Figure 6A, 6B, Supplemental online video 6).

Percutaneous hepatic access has been used for achieving long term vascular access in patients requiring hemodialysis, (11) total parenteral nutrition (12) and chemotherapy (13). Additionally, the use of this approach for cardiac catheterization procedures has been well described in the pediatric literature (14-24). The large caliber of hepatic veins makes them well suited to accommodate sheaths used for percutaneous catheter ablation procedures. Additionally, the inferior approach increases catheter stability and is optimal for procedures such as RA isthmus ablation and transseptal catheterization and pulmonary vein isolation.

From a safety perspective, a low complication rate has been reported for common non-cardiac procedures (such as portal venous catheterization and percutaneous transhepatic cholangiography) which utilize percutaneous hepatic venous access. Additionally, Shim and colleagues reported a complication rate of less than 5% when transhepatic venous access was obtained for invasive cardiac procedures in a pediatric population (20). However, this procedure must be performed with care to avoid complications. Specifically, transaminitis, hemorrhage, cholangitis, liver abscess, sepsis, hepatic vein thrombosis, gallbladder perforation and pneumothorax may occur.
Appropriate landmarking and use of imaging (such as ultrasound and fluoroscopy) may minimize complications associated with this procedure.

In both of our cases, ultrasound guidance (trans-cutaneous and trans-esophageal) was useful to visualize the hepatic veins. In addition to minimizing radiation exposure, ultrasound is advantageous since: i) it allows for real-time visualization of the hepatic vein thereby permitting the operator to select a suitable site to obtain percutaneous access, ii) it allows the operator to visualize the relationship between the needle and the vein to help orient the trajectory of the needle, and iii) it allows the operator to monitor for complications such as a sub-capsular hematoma. Such detailed soft tissue visualization is not possible with use of fluoroscopy alone. This approach may also minimize the number of punctures necessary to achieve access (28).

Varying approaches have been used to achieve hemostasis of the tract created in the liver parenchyma. While some operators have simply used manual pressure or placed patients in the right lateral decubitus position (18, 23), others routinely achieve hemostasis with the placement of intra-hepatic coils (14, 19) or Gel Foam (16). In the first patient of our report, a novel method of achieving hemostasis was employed – that is, bipolar radiofrequency energy to cauterize / coagulate the adjacent liver parenchymal tissue. This approach may be advantageous compared to the placement of coils or Gel Foam as it may avoid the potential complication of embolization of the coil or Gel Foam. A vascular plug was placed in the hepatic tract in patient #2. Care was taken to ensure that the plug was not placed within the hepatic vein itself where it could act as a nidus for thrombus resulting in hepatic vein thrombosis. Regardless of the method employed to achieve hemostasis, one must be vigilant for ongoing hemorrhage. Computed
tomography and ultrasonography are useful diagnostic modalities to identify the presence of hemoperitoneum. Should this occur, a decision regarding the need for conservative management or surgical exploration is necessary. In both cases, our patients were monitored in an intensive care setting post-procedure as both patients were anti-coagulated.

In conclusion, percutaneous trans-hepatic catheterization is a feasible alternative to performing invasive electrophysiology procedures when venous access is limited. The judicious use of pre- and intra-procedural imaging may facilitate the ease and safety of performing these procedures.

Conflict of Interest Disclosures: None

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Figure Legends:

**Figure 1: Congenital absence of the inferior vena cava (IVC).**  
**A:** Scheme of the most common form of congenital absence of the IVC. The segment of the IVC between the renal and hepatic veins is absent with venous return from the lower extremeties returning to the right heart via the azygous / hemi-azygous system. Hepatic blood flows directly into the right atrium.  
**B:** Transverse plane CT image showing the direct connection between a hepatic vein and the single atrium in patient #1.  
**C:** Saggital plane CT image showing the direction connection between a hepatic vein and the single atrium, and absence on an inferior vena cava, in patient #1.

**Figure 2: Electroanatomical map for patient 1.**  
**A:** 12 lead electrocardiogram demonstrating the clinical arrhythmia for patient #1 - atrial flutter with 2:1 AV conduction.  
**B:** Integration of the 3 dimensional CT rendering of the single atrium for patient 1 with a CARTO electroanatomic map created using the Niobe II magnetic navigation system (also see supplemental online video 3). Using a timing reference placed in the azygous vein, an activation map of the clinical arrhythmia was created, and is displayed in this panel. Regions with early activation are represented by the red color whereas regions with late activation represented by the purple color on this activation map. The activation sequence was consistent with a macro-reentrant arrhythmia coursing around the AV valve. Areas with a good post-pacing interval during entrainment are indicated by the green dots, whereas areas with poor post-pacing intervals during...
entrainment are indicated by blue dots. Ablation was performed in the isthmus between the single AV valve and confluence of hepatic veins entering the atrium.C: Demonstration of isthmus block with differential pacing. A duo-decapolar catheter is placed within the single atrium. The conduction time when pacing from electrode pair at 9-10 (blue dot) to the electrode pair at 5-6 (red dashed circle) was 206msec.D: Demonstration of isthmus block with differential pacing. A duo-decapolar catheter is placed within the single atrium. The conduction time when pacing from electrode pair at 11-12 (blue dot) to the electrode pair at 5-6 (red dashed circle) was 186msec. The presence of a conduction time when pacing from electrode pair 11-12 compared to 9-10 was consistent with block across the isthmus.

**Figure 3:** Ultrasound guided approach for obtaining percutaneous hepatic vein access. A: A trans-cutaneous ultrasound probe with sterile covering is used to visualize a hepatic vein. The angulation of the percutaneous needle is oriented in a similar fashion to the imaging probe to facilitate access to the hepatic vein. B: Visualization of a hepatic vein with the trans-cutaneous ultrasound probe. C: The percutaneous needle tip (indicated by the arrow) can be visualized with the ultrasound probe as it enters the hepatic vein. D: Confirmation of entrance into the hepatic vein can be achieved by injecting contrast through the percutaneous needle (indicated by the arrow). If hepatic vein access is successful, then echo-contrast can be visualized in the hepatic vein (see also supplement online video 1).

**Figure 4:** Achieving hemostasis at the completion of the procedure. A: Bipolar radiofrequency probe (highlighted with dashed oval) employed in patient # 1 to cauterize
coagulate the hepatic tissue along the tract created with the 8Fr vascular sheath. **B:** Placement of a vascular plug in the hepatic tract to achieve hemostasis in patient #2. The long transseptal vascular sheath is exchanged for a short vascular sheath which is placed just outside the hepatic vein. Contrast is injected through the short vascular sheath to demonstrate the position of the sheath in relation to the hepatic vein. The sheath and undeployed vascular plug, is placed just outside the hepatic vein. The vascular plug is deployed (by simply withdrawing the sheath over the plug) at a site just outside the hepatic vein (see also supplemental online video 5). **C:** Fluoroscopic image of the deployed vascular plug. **D:** Ultrasound image of the deployed vascular plug (indicated by the arrow) confirming its deployment outside of the hepatic vein.

**Figure 5: Fluoroscopic approach for obtaining percutaneous hepatic vein access. A:** A quadripolar catheter is placed in the coronary sinus via the azygous vein and left superior vena cava. A decapolar catheter is placed in a hepatic vein using via the right internal jugular vein. The percutaneous 22Ga spinal needle (arrow) is directed towards the hepatic vein whose course is highlighted by the decapolar catheter placed within the hepatic vein. Contrast is injected during insertion of the percutaneous needle to demonstrate entrance into the hepatic vein. **B:** Once hepatic venous access is achieved then an angioplasty wire is advanced in to the right atrium. Note the presence of a transesophageal echocardiogram probe. **C:** The hepatic tract is then dilated with a 6Fr dilator and the angioplasty wire exchanged for a 0.035 inch guidewire. **D:** Once the hepatic tract is dilated and a 0.035 inch guidewire is placed in the right atrium a long transseptal sheath is placed in the right atrium and transseptal puncture performed. **A**
deflectable transseptal sheath is seen in the left atrium in this panel. The quadripolar catheter remains in the coronary sinus. The decapolar catheter which was initially placed in the hepatic vein is now repositioned in the coronary sinus. Note the presence of a transesophageal echocardiogram probe (See supplemental online video 5).

**Figure 6: CT reconstruction of patient 2’s left atrial anatomy.** A: Postero-anterior view of the CT reconstruction of the left atrium, right atrium, left superior vena cava and coronary sinus for patient #2 fused with an electroanatomic map created with the NavX system. Ablation lesions are denoted by the white points. B: Left anterior oblique view of the CT reconstruction of the left atrium, right atrium, left superior vena cava and coronary sinus for patient #2 fused with an electroanatomic map created with the NavX system. Ablation lesions are denoted by the white points.
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SUPPLEMENTAL MATERIAL

Supplemental Online Video 1: Confirmation of entrance into the hepatic vein using ultrasound guidance.

Supplemental Online Video 2: Fluoroscopic images during percutaneous access in patient #1.

Supplemental Online Video 3: Aortic registration to facilitate integration of a pre-acquired CT scan of single atrium in patient #1.

Supplemental Online Video 4: Activation / propagation map demonstrating a macro-reentrant atrial arrhythmia around the single AV valve in patient #1.

Supplemental Online Video 5: Fluoroscopic approach to obtaining percutaneous trans-hepatic access to the left atrium and achieving hemostasis with deployment of a vascular plug in patient #2.

Supplemental Online Video 6: Fusion of a pre-acquired CT scan of the left atrium, right atrium, coronary sinus and left superior vena cava with an electroanatomic map created with the NavX system.