

Percutaneous MR Imaging–guided Transvascular Access of Mesenteric Venous System: Study in Swine Model¹

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Purpose:

To determine if, with use of magnetic resonance (MR) imaging guidance alone, transcaval puncture of the superior mesenteric vein (SMV) and/or portal vein is feasible with a percutaneous femoral vein approach.

Materials and Methods:

The Institutional Animal Care and Use Committee approved the animal studies. Ten inferior vena cava (IVC)–SMV punctures were performed in six pigs. An active MR intravascular needle system was used for all transvascular punctures, and all procedures were performed with a 1.5-T MR unit. The needle was introduced via a 12-F femoral vein sheath and advanced into the IVC by using a real-time gradient-recalled-echo sequence (3.4/1.2 [repetition time msec/echo time msec], 45° flip angle, and six to eight frames per second). Fast transverse spoiled gradient-recalled acquisition in the steady state (SPGR) (6.0/1.5, 60° flip angle, one frame per second) was performed to confirm needle trajectory. The needle system was advanced under real-time MR imaging to puncture the SMV. The location of the needle tip was confirmed with a fast spin-echo sequence (1904/4.5, 36-cm field of view). A direct MR portogram was obtained after the administration of gadopentetate dimeglumine at a concentration of 25% with fast SPGR (6/1.3, 90° flip angle, no section selection, three frames per second). Success was defined as entry into the mesenteric venous system without traversal of any retroperitoneal organs or adjacent vasculature.

Results:

Successful MR imaging–guided IVC–SMV punctures were performed in all 10 procedures (100%). The needle was fully visualized as it traversed the retroperitoneum and entered the SMV. MR portograms were successfully obtained following all punctures through the needle. Conventional transverse MR imaging helped confirm that the needle did not traverse any retroperitoneal organs or vessels.

Conclusion:

With use of only MR imaging guidance and an active MR imaging intravascular needle system, the authors were able to successfully puncture the SMV from the IVC with direct visualization of the needle and all retroperitoneal structures.

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Because of anatomic concerns, direct percutaneous puncture of the superior mesenteric vein (SMV) or splenic vein currently cannot be performed safely with conventional radiographic guidance. Current strategies for accessing the splenic vein or SMV include transhepatic puncture of the portal vein, puncture of the portal vein with a transjugular approach, and direct surgical exposure of the mesenteric veins. Although the transjugular and transhepatic approaches into the portal vein are well-established techniques, both are performed by advancing a needle into the parenchyma without direct visualization of the portal vein. The main advantage of a transjugular approach is that the portal vein can be accessed without traversing the liver capsule, so the risk of bleeding complications is reduced in patients with underlying coagulopathy or ascites. Transhepatic approaches are favored by many interventionalists because they provide a better mechanical advantage for manipulating catheters and wires. Both techniques, however, necessitate multiple needle passes to opacify the portal vein. In addition, when the portal vein is accessed with fluoroscopy, direct visualization of organs such as the pancreas, liver, and spleen is not feasible.

Magnetic resonance (MR) imaging is an attractive modality for vascular imaging because it provides superior soft-tissue resolution and three-dimensional anatomic information without the need for ionizing radiation or iodinated contrast material. Because of the increased speed of MR imaging acquisitions and the development of device and/or cath-

eter tracking technology, MR imaging-guided vascular procedures are now feasible (1). Therefore, an alternative access into the mesenteric and splenic venous system with MR imaging guidance may provide an opportunity to direct transvascular therapies into this separate and isolated venous system. Furthermore, safe and reliable access may provide alternative therapeutic options for conditions such as portal hypertension or portal vein thrombosis. The ability to accurately perform an invasive procedure such as MR imaging-guided transvascular puncture requires the ability to (a) monitor viscera and the vasculature in a real-time environment, (b) fully visualize and track an intravascular needle with MR imaging, and (c) provide adequate spatial resolution for identifying the SMV and adjacent structures before puncture of this vessel with a needle. Thus, the purpose of our study was to determine if, with use of only MR imaging for guidance, transcaval puncture of the SMV and/or portal vein is feasible with a percutaneous femoral vein approach.

Materials and Methods

Animal Model

The institutional animal care and use committee of Johns Hopkins Medical Institutes approved the animal studies. We performed experiments in six healthy pigs weighing 40–45 kg. Sedation was achieved with xylazine and ketamine. After endotracheal intubation, inhaled 2% isoflurane was provided during mechanical ventilation with 98%

oxygen. Percutaneous access into the right femoral vein was achieved by using ultrasonographic guidance. Then, a 12-F sheath was placed into the femoral vein. All animals were transferred to the MR imaging suite for the remaining portion of the procedure.

Needle Design

The design of the active MR needle, which is manufactured in our laboratory (by P.V.K. and E.A.), is shown in Figure 1. This needle is made of concentrically configured nitinol hypotubings arranged to form a loopless antenna (2). The intravascular needle antenna is made of two thin-walled nitinol tubes with a central lumen that can accommodate a 0.038-inch guidewire. Therefore, the antenna can be safely advanced over the wire by means of a femoral vein approach. The needle system has a caliber of 9 F, with a sharpened bevel at the end. To facilitate punctures, the shaft is pre-shaped at the distal tip to provide a 55° bend, which results in a needle trajectory that is perpendicular to the caval wall. The inner lumen of the inner tube is further insulated with a liner that electrically insulates the system and acts as a guidewire lumen (compatible with a 0.038-inch wire). Except for the distal

Figure 1

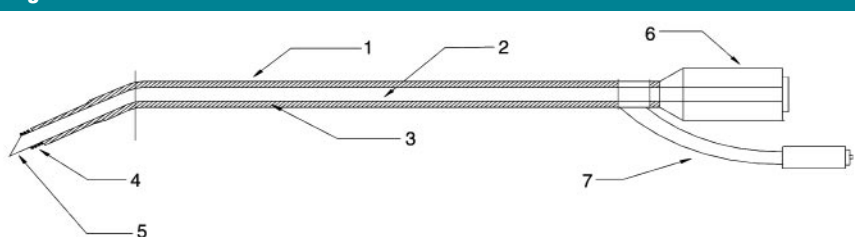


Figure 1: Schematic of the needle assembly. 1 = Outer nitinol tube, 2 = inner nitinol tube with a polyimide liner, 3 = nylon dielectric, 4 = copper wire coil, 5 = three-face bevel, 6 = Luer connector for syringe, 7 = coaxial cable connector to interface circuit.

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Abbreviations:

GRE = gradient-recalled echo
IVC = inferior vena cava
SMV = superior mesenteric vein
SPGR = spoiled gradient-recalled acquisition in the steady state

Author contributions:

Guarantors of integrity of entire study, A.A., P.V.K., E.A.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; literature research, A.A., P.V.K., C.R.W.; clinical studies, A.A.; experimental studies, all authors; statistical analysis, A.A., C.R.W.; and manuscript editing, all authors

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tip of the tube, the entire assembly is insulated with nylon to isolate the needle components from direct electrical contact with biologic fluids. The radio-frequency circuitry matches the radio-frequency transmission at 63.86 MHz to enable active tracking (3) (Fig 2). For the transvascular punctures, the distal tip of the needle was oriented in the direction of the puncture. A second standard nitinol guidewire (EV3, Plymouth, Mass) that had been modified so that the tip (0.035 inch) was sharpened was advanced 1 cm outside the active needle to facilitate the puncture.

Technique and Definition of Success

The entire procedure was performed solely under MR imaging guidance with a 1.5-T unit (CV/i; GE Medical Systems, Waukesha, Wis). Images were obtained by using a combination of external phased-array coils and the intravascular needle. The needle was introduced from the common femoral vein through a standard 12-F vascular sheath and advanced over a 0.035-inch nitinol guidewire (EV3).

All procedures were performed by an experienced interventional radiologist (A.A., with 5 years of experience as an interventional radiologist). During the procedure, the interventionalist advanced the needle by using an imaging console adjacent to the MR unit to monitor needle tracking and orientation. A second radiologist (C.W., with 2 years of research in MR imaging and 1 year of clinical residency training) controlled imaging parameters and section orientation on the basis of the feedback of the interventionalist. The needle was positioned in the inferior vena cava (IVC) and rotated to the correct orientation by using a real-time GRE sequence. The needle was readily tracked at all times, and multiple projections were used to help confirm needle position throughout the procedure.

With use of the real-time GRE sequence (3.4/1.2 [repetition time msec/echo time msec], 45° flip angle, 30-cm field of view, six to eight frames per second) in combination with an interactive imaging plane acquisition (i-Drive; GE Medical Systems), the needle was

Figure 2

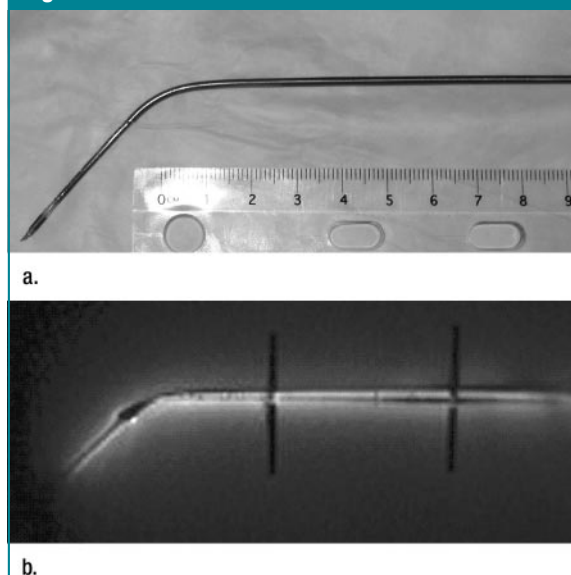


Figure 2: (a) Photograph of the intravascular prototype needle antenna. Scale is in centimeters. (b) Fast gradient-recalled-echo (GRE) MR image (3.5/1.1, 45° flip angle) of the needle in a saline phantom. The linear artifact along the shaft is caused by the acrylic material that supports the needle in the phantom model.

advanced into the IVC and guided to the level where the SMV is closest to the IVC (Fig 3a, 3b). With fast SPGR (6.0/1.5, 60° flip angle, 35-cm field of view, one frame per second), needle trajectory, orientation, and surrounding retroperitoneal structures were evaluated (Fig 3c).

After proper orientation of the active needle toward the target vessel, the needle path was examined to confirm that no vessels or retroperitoneal structures would be inadvertently injured. Next, a second standard nitinol guidewire (EV3) with a sharpened tip was coaxially introduced. The sharpened tip was advanced 1 cm outside the active needle to facilitate puncture; passive tracking of the sharpened tip was used to monitor the progress of the needle as it exited the IVC and entered the SMV. With the real-time GRE sequence and multiplanar views, the entire system (sharpened needle and active needle) was advanced as a unit until the SMV was entered. After removal of the sharpened guidewire, the immediate return of blood through the active needle helped confirm that the SMV was successfully punctured. After removal of the guidewire, a direct MR portogram was obtained through the needle by using 10 mL of gadopentetate dimeglumine (Magnevist; Berlex Imaging, Montville, NJ) at a concentration of

25% (fast SPGR, 6/1.3, 90° flip angle, no section selection, 0.5 signal acquired, 45.0 × 22.5-cm field of view, three frames per second) (4). To help confirm needle position and to determine whether other organs or vessels were inadvertently traversed during the procedure, repeat imaging of the retroperitoneum was performed with an electrocardiographically gated fast spin-echo sequence by using a double-inversion black blood technique (1904/4.5, 62.5-kHz bandwidth, 3-mm-thick sections, 36-cm field of view, 256 × 128 image matrix, and one signal acquired). A puncture was considered successful if the needle was advanced from the IVC to the SMV without traversal of any retroperitoneal structures and a direct MR portogram could be obtained.

In four animals, when MR imaging time allowed, another puncture was performed, so two separate punctures were made. After the needle was removed completely from the femoral sheath, repeat imaging with a 10-minute delay was performed with a fast SPGR sequence (6.0/1.5, 60° flip angle, 35-cm field of view, one frame per second) to assess the vasculature for thrombosis and determine whether there was any displacement related to retroperitoneal bleeding. After it was confirmed that there was no retroperitoneal bleeding,

the needle was reintroduced into the femoral vein sheath to perform the second puncture.

A puncture was defined as advancement of the needle from the IVC to the SMV. A pass was defined as an attempt to puncture the SMV. In addition to success rates, the optimal imaging parameters and the number of passes required for each successful procedure were noted.

Results

Success Rates

MR imaging–guided puncture of the SMV was successfully performed in all six pigs. All procedures were performed with real-time MR imaging by using free-breathing techniques and without electrocardiographic gating. Punctures were performed with no change in cardiac rhythm or rate and with no sequelae. Ten punctures were performed in six swine. All 10 procedures were successful (100%), with direct puncture of the SMV and no traversal of any retroperitoneal organs and/or vessels, as demonstrated with an electrocardiographically gated fast spin-echo double-inversion black-blood sequence (Fig 4). MR portograms were immediately ob-

tained after all punctures (Fig 5). Two punctures were made in four animals. After removal of the needle from the first puncture, delayed imaging did not demonstrate retroperitoneal bleeding in any of the pigs.

Imaging Parameters

Because of the mobility of the SMV, real-time imaging of all punctures was necessary to reorient the needle toward the SMV in order to enter the vessel. During real-time GRE sequences, four to eight frames per second were possible throughout the procedure. Routine transverse imaging after each puncture helped confirm that the needle entered the SMV without traversing other retroperitoneal structures (Fig 4).

Three standard views were used with the real-time sequence for each puncture. A sagittal view of the IVC (real-time GRE) was used to track the entry of the needle and provide directionality and orientation of the needle (Fig 3a). A short transverse view of the abdomen (fast SPGR and real-time GRE) was used to identify the relationship of the needle to the IVC, SMV, and retroperitoneal structures (Fig 3b, 3c). Finally, an oblique sagittal view along the needle tip (real-time GRE) was used to monitor the path of the needle as it

exited the IVC and entered the SMV. During the procedure, the interventionist was able to immediately change any of these prescribed planes. In all punctures, an immediate return of blood was noted from the needle hub; this was followed by the obtaining of a confirmatory portogram (Fig 5). The typical duration of each puncture was approximately 10–40 minutes. This period began with the insertion of the needle into the femoral vein and ended once the needle penetrated the SMV and the confirmatory portogram was obtained. Repeat thin-section imaging of this area after each puncture demonstrated no retroperitoneal bleeding.

Number of Passes

For each puncture attempt, it was necessary to perform an average of one to three separate passes from the IVC once the active needle was outside the IVC. With each pass, multiplanar imaging helped confirm that retroperitoneal structures were not injured or traversed. Repeat delayed imaging in animals that underwent a second puncture showed no bleeding into the retroperitoneum, no vascular hematomas, and no change in orientation of the vasculature after removal of the intravascular needle.

Figure 3



Figure 3: Real-time puncture of SMV from IVC with intravascular needle. (a) Sagittal real-time GRE MR image (3.4/1.2, 45° flip angle). The needle is introduced through a femoral vein and oriented to the SMV. Arrowhead = tip of needle, arrow = IVC. (b) Transverse real-time GRE MR image (4.4/1.3) shows needle being advanced to the SMV. Arrowhead points to the needle, long arrow points to the IVC, and short arrow points to the SMV. (c) Transverse MR image obtained with fast spoiled gradient-recalled acquisition in the steady state (SPGR) (6.0/1.5, 60° flip angle) as needle enters the SMV; note indentation of needle on posterior wall of SMV.

Figure 4



Figure 4: (a) Transverse fast spin-echo MR image (1900/4.5, 90° flip angle) shows that the intravascular needle (area of high signal intensity indicated by arrow) has exited the IVC. The SMV is located anteriorly, and the needle (arrow) is seen heading toward the SMV. (b) Transverse MR image (2000/18.0) shows the needle in the SMV (arrow). (c) Sagittal fast spin-echo MR image (2000/18, 90° flip angle) demonstrates the needle (black arrow) superior to a loop of bowel (white arrow) and puncturing the SMV (arrowhead). Notice that the SMV is displaced anteriorly with the puncture.

Discussion

Because of the invasiveness of transcaval punctures and the potential for injury to various retroperitoneal structures, we developed an active MR intravascular needle that can be completely visualized in an MR imaging environment and used to perform MR imaging-guided extravascular punctures. In addition to monitoring the needle, we were able to visualize all viscera and pertinent vascular structures to perform this procedure. The use of this needle, in combination with real-time and fast GRE MR imaging, enabled adequate temporal and spatial resolution so that active tracking of the needle during transcaval punctures was possible. The results of this study demonstrate that MR imaging-guided puncture of the SMV is feasible in a swine model.

Because of anatomic concerns, direct percutaneous puncture of the SMV or splenic vein currently cannot be performed safely with conventional radiographic guidance. Because of the anatomic variability in the relationship of these vessels to the IVC and the close proximity of adjacent vessels and organs (eg, aorta, superior mesenteric artery, and pancreas), the advancement of a needle into the retroperitoneum cannot be performed solely under con-

Figure 5

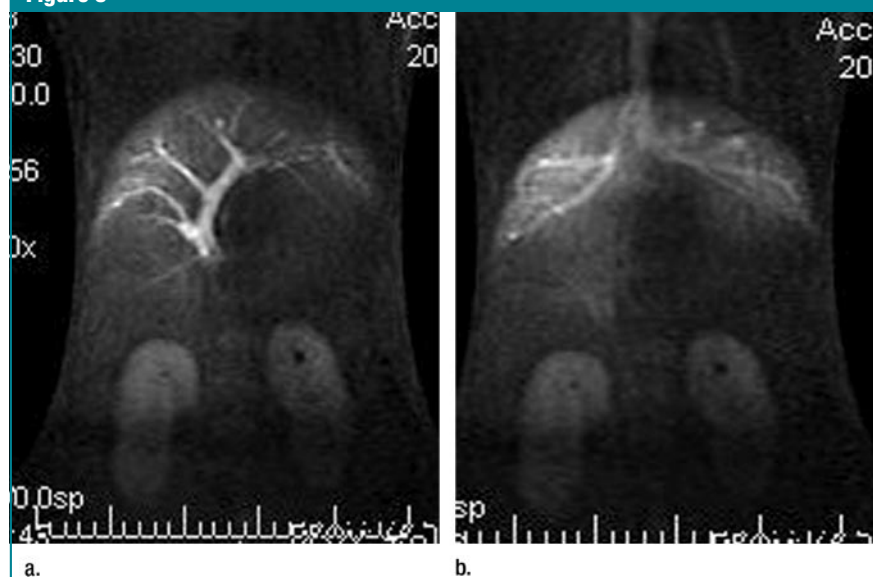


Figure 5: (a, b) MR Portograms obtained (a) in the vascular and parenchymal phases and (b) in the hepatic parenchymal phase after the administration of gadopentetate dimeglumine by using a projection image (fast SPGR, 6/1.3, 90° flip angle, 1.5 frames per second).

ventional radiographic guidance. Both the portal and splenic veins lie in the anterior pararenal space of the retroperitoneum, adjacent to the pancreas. The main trunk of the SMV is embedded in extraperitoneal fat within the mesentery and located anterior to these retroperitoneal structures. The IVC is

also located in the retroperitoneum, but posterior to the SMV, splenic vein, and portal venous system (5). Because these vessels are also surrounded by bowel, a conventional percutaneous approach is precluded. In addition, the portal, splenic, and SMV systems are isolated from the systemic circulation and can-

not be readily visualized with conventional contrast material injections.

Because of these anatomic constraints, the percutaneous puncture of the mesenteric or splenic venous system has undergone limited study. Kaminou et al (6) first described a percutaneous approach to the splenic vein from the IVC by using only radiographic fluoroscopy. In a swine model, the portal vein was directly punctured; then, a wire basket was placed in the splenic vein to serve as a target. Next, a second needle puncture was performed from the IVC into the wire basket inside the splenic vein. With this procedure, a shunt was successfully created in four of five pigs. In all four successful punctures, however, necropsy demonstrated that the needle and stent were placed through the pancreas. In addition to being fairly cumbersome and necessitating extensive fluoroscopy, the inability to visualize retroperitoneal structures limited the usefulness of this technique.

In a more recent study, Vivas et al (7) attempted to create an extrahepatic portal caval shunt in a canine model. With use of jejunal veins from the mesentery that were exposed after a laparotomy, the SMV and portal vein were catheterized. After placement of another catheter in the IVC, a blind puncture was made from the portal vein into the IVC. With this access, a covered prosthesis was placed to simulate a portal caval shunt. Because of the lack of visibility and poor placement of the prosthesis, however, six of the 10 animals died after the procedure owing to substantial retroperitoneal bleeding that resulted from multiple vascular punctures. Both of these studies further reinforce the importance of visualizing the retroperitoneum during these invasive procedures.

In our study, all punctures were performed in a controlled fashion because all vasculature and viscera were readily visualized. The real-time GRE sequence enables rapid data acquisition with direct manipulation of section prescription, flip angle, section thickness, and field of view—all in a real-time setting.

With use of this system, adequate visualization of both the vasculature and viscera was possible without the need for contrast material. This system provided several advantages: (a) All vessels were completely visualized with the transverse imaging plane because of the T2 and/or T1 effects the GRE sequence has on blood; (b) rapid multiplanar capabilities enabled us to monitor the transcaval punctures; and (c) there was adequate temporal resolution to perform real-time manipulation of the needle. The use of this system provided substantial improvement for obtaining multiplanar views to identify a needle trajectory.

We did, however, notice difficulty in identifying vascular structures with the real-time GRE sequence alone. Because there was increased signal from other adjacent tissue, it was difficult to properly identify the vasculature. Therefore, the adjunctive use of a transverse SPGR sequence with real-time temporal resolution helped properly identify the vasculature for a proper needle trajectory.

The limitations of this study are related to safety. Because this is a first-generation device, radiofrequency safety issues have not yet been fully analyzed. Insulation is known to improve the possible radiofrequency safety problems, and it is also possible to limit the delivered radiofrequency power level with the pulse sequences used. We plan to measure the safety index—the expected temperature increase caused by the needle for a given unit of specific absorption rate distribution—and adjust the power level accordingly (8). Finally, although MR imaging did not depict any retroperitoneal bleeding or nontarget punctures, pathologic analysis of the vessels and retroperitoneum structures was not performed; therefore, the safety of this procedure is not known.

In conclusion, we found that with use of only MR imaging guidance and an active MR intravascular needle system, we were repeatedly able to successfully puncture the SMV from the IVC in a highly controlled manner with direct vi-

sualization of all components including the needle, IVC, SMV, and surrounding abdominal organs. The multiplanar capability of MR imaging, combined with its excellent soft-tissue resolution, enabled us to identify a needle trajectory for direct, accurate punctures of the SMV.

Practical application: Because of anatomic concerns, direct percutaneous puncture of the SMV or splenic vein currently cannot be performed with conventional radiographic guidance. MR imaging guidance enabled us to simultaneously visualize and puncture the SMV. In addition, a minimally invasive means of accessing the portal, mesenteric, and splenic venous system may create unique treatment opportunities such as the creation of a mesoportocaval shunt or MR imaging-guided transvascular delivery of agents to target organs such as the liver, pancreas, or spleen.

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