LIVER DUPLEX EXAMINATION

INTRODUCTION

The liver is the largest organ in the body and has many functions. Many of these functions are related to metabolism of the products involved in digestion, filtration and detoxification of the blood. Typically a routine abdominal ultrasound exam relies on gray-scale imaging of the structures throughout the abdomen. In these cases, Doppler is used mainly to differentiate vascular from non-vascular structures. A liver duplex examination focuses on the portohepatic circulation and the liver vasculature can be visualized adequately for assessment in the majority of cases. Ultrasound system advances have increased the frequency of successful portal venous system evaluation to over 90%. This online course is going to cover how to perform a thorough liver Doppler examination to assess the hepatoportal circulation. Common liver pathology will be introduced followed by a review of the anatomy and physiology of the liver, spleen and portohepatic circulation. A full liver duplex examination technique will be described including proper patient positioning, ultrasound assessment and interpretation of the organs and blood flow for normal and abnormal situations.

LIVER DISEASE

Cirrhosis is the most common cause of liver disease related to portal hypertension in the United States. Portal hypertension is defined as elevated pressures within the portal circulation. If the portosystemic pressure gradient increases more than 10mmHg, it causes portal hypertension. The pressure gradient results from an increase in parenchymal resistance to portal venous flow. This is usually the result of inadequate filtration at the hepatocellular level. The increased resistance causes the body to attempt to compensate by increasing splanchnic flow which increases portohepatic congestion. Ultimately it can result in reversal of flow throughout the portal system and the development of collaterals and varices to compensate for the increased blood volume. This can cause splenomegaly, ascites and hepatic encephalopathy, which is the end result of the deterioration of liver function where ammonia builds up in the blood. Additionally, patients with cirrhosis are at a higher risk of developing hepatocellular carcinoma. Portal hypertension can be divided into its underlying causes related to prehepatic, intrahepatic and post-hepatic etiologies. This system divides the pathologies into their primary site that is causing the original increase in vascular resistance. Pre hepatic etiology would include portal or splenic vein thrombosis or extrinsic compression. Intrahepatic causes are the most common with cirrhosis accounting for approximately 90% of all portal hypertension. Others could include hepatic fibrosis or lymphoma. Post-hepatic etiologies are most likely from inferior vena cava or hepatic vein obstruction or hepatic artery obstruction. Schistosomiasis is another common cause for portal hypertension and is a disease caused by parasitic worms found in contaminated water. The most common locations where schistosomiasis is found are in Africa, Asia and South America. Bud-Chiari syndrome is a post-hepatic etiology and is defined as stenosis or obstruction of the hepatic veins. This hepatic outflow obstruction could be from extrinsic compression by a tumor, hepatomegaly, ascites or thrombosis. As portal

hypertension progresses, it may cause ascites, splenomegaly, gastroesophogeal bleeding, jaundice and other signs of liver failure. One treatment method often used to help decompress the liver is the placement of a stent. This procedure is called a TIPS, which stands for transjugular, intrahepatic portosystemic shunt. A stent is inserted into the right portal vein, through the liver parenchyma and joins back into the right hepatic vein. The purpose of a TIPS is exclusively to decompress the liver by shunting the blood from the portal to the systemic system and bypassing the filtration through the liver parenchyma. It reduces the risk of ruptured varices; however does not address the cause of the portal hypertension. Patients with severe end stage liver disease may also be candidates for liver transplantation and ultrasound is also used for post-transplant evaluation.

ANATOMY

The liver is the largest organ in the body and located predominately in the right upper quadrant. The superior, anterior and some of the posterior surface of the liver is bounded by the diaphragm. The inferior liver surface is in contact with other visceral organs. It can be divided into lobes and segments by the vessels, ligaments and fossas that course throughout the parenchyma. The main lobes are the right lobe, the left lobe and the caudate lobe. The right lobe is the largest section and contains approximately 2/3rds of the parenchyma. The left lobe is smaller and can be more variable in size. The smallest lobe is the caudate lobe. It is located midline and posterior to help separate the right and left lobes. The hepatic veins of the liver serve as dividers between the lobes and segments. The middle hepatic vein divides the right and left lobes. The right lobe is divided into anterior and posterior sections by the right hepatic vein. The left lobe is divided into medial and lateral sections by the left hepatic vein. The left intersegmental fissure also serves as a divider for the medial and lateral sections of the left lobe. The ligamentum teres or round ligament is a remnant of the umbilical vein of a fetus and is located within this fissure. The falciform ligament is located in the fissure and attaches the liver to the anterior body wall. The caudate lobe is bounded laterally by the ligamentum venosum and medially by the inferior vena cava. The three hepatic veins that help divide the liver into its various segments are responsible for draining the liver parenchyma. They converge with the inferior vena cava in the most superior and posterior part of the liver at the diaphragm. Anatomic variations could include duplication of the left hepatic vein or accessory hepatic vein, absence of one of the three hepatic veins, or convergence of the middle hepatic vein with the left prior to the inferior vena cava confluence.

The portal veins course within the liver segments previously described. The main portal vein is formed by the confluence of the superior mesenteric and splenic veins. This junction converges posterior to the pancreatic neck. The portal vein courses obliquely and to the patient’s right side into the portahepatis. It then bifurcates into right and left branches entering the right and left lobes respectively. The splenic vein is located posterior to the pancreas and follows a relatively straight course from the hilum of the spleen. This is opposite of the splenic artery which generally has a very tortuous path to the splenic hilum. The body and tail of the pancreas are in alignment with the splenic vein course, so the pancreas is an excellent anatomic landmark for the splenic vein and vice versa. The superior mesenteric vein courses from the mesentery and runs parallel to the superior mesenteric artery, the inferior vena cava and the aorta. The other tributaries of the portal venous system include the coronary vein, also known as the left gastric vein, and the inferior mesenteric vein. The inferior mesenteric vein may confluence with the splenic vein or the splenic/superior vein junction and follows a similar path as the inferior mesenteric artery. The coronary vein courses along the posterior aspect of the stomach towards the gastroesophageal junction. It usually joins with the portal venous system at the portosplenic junction.

The portal vein itself has thick walls, more like the thick walled arteries than thin walled veins. As it enters the liver, it travels with two other vessels, the proper hepatic artery and common hepatic duct. These three vessels together are called the portal triad. The hepatic duct is lateral, the hepatic artery is medial and the portal vein is posterior. They are bound together by echogenic fibrous tissue called the Glisson's capsule. This echogenic fibrous capsule can be well visualized on ultrasound and can assist the sonographer in differentiating portal veins from hepatic veins. The right and left portal veins pass through the liver parenchyma in a transverse fashion. The portal veins are larger at the portahepatis and become smaller as they get deeper within the liver parenchyma. The portal venous system carries nutrient-rich blood from the intestines and delivers it to the liver for processing and filtering. It is responsible for 70-80% of the liver's blood supply. The hepatic artery also supplies oxygen rich blood to the liver. The common hepatic artery is a branch off of the celiac artery and courses toward the liver. The common hepatic artery changes its name to the proper hepatic artery, after the gastroduodenal artery branches off. It then courses with the portal vein to the portahepatis. Once inside the liver, it divides into the right and left hepatic arteries and penetrates into the hepatic parenchyma. The most common anatomic variations are the common hepatic or right hepatic artery originating directly from the superior mesenteric artery or the left hepatic artery originating from the left gastric artery, which is a branch from the celiac artery.

LIVER DUPLEX EXAM

This examination yields the best results with the patient being fasted overnight and the exam performed first thing in the morning to minimize the negative effects of overlying bowel gas. This is true for many other abdominal imaging ultrasound exams as well as other imaging modalities. A lower frequency transducer should be used to achieve adequate penetration. A curved linear array or a phased array sector transducer with frequencies ranging from 2-5 MHz as well as a higher 5-7MHz transducer should be available. Initially the patient is asked to lie on the examination table in a relaxed supine position; however, the exam will require the patient to move into the right and left lateral decubitus positions. Windows used during the exam should include anterior abdomen, subcostal and intercostal. This exam will require two major components, the b-mode assessment of the liver and then the Doppler assessment of the circulation. When pulsed wave Doppler is used, angles of insonation should always be $\leq$ 60 degrees and the cursor aligned parallel to the vessel walls with the sample positioned center stream. B-mode assessment begins with sweeping the transducer throughout the liver parenchyma in a systematic fashion to assess for normal homogeneous and moderately echogenic liver parenchyma. This can be accomplished by using the normal divisions of the liver lobes and slowly and methodically sweeping through the parenchyma and documenting images based on normal liver landmarks. For example, begin in a transverse imaging plane in the sub-xiphoid space and sweep through the left liver lobe from superior to inferior and back. Equipment settings should show even echoes from anterior to posterior on the image, overall gain should show moderate liver echogenicity, focus should be at or below the posterior borders of the left lobe and depth should be approximately 2-3cm below the posterior left lobe border. Throughout the sweeping motion, all liver borders should be visible including anterior and posterior as well as lateral and medial borders. The most medial border when sweeping through the left lobe can be the inferior vena cava. Image documentation can be 2-3 representative images and usually include a still image of the left lobe with hepatic veins, left lobe with the left portal vein and finally a left lobe image inferior to the left portal vein. The goal of these images should be to center as much of the liver tissue on the image as possible. Do not center the images based exclusively

on the described landmarks. Once the transverse left lobe evaluation is complete, rotate the transducer to a sagittal imaging plane and then sweep through the left lobe beginning at the IVC and moving laterally. The equipment setting can remain the same as they were for the transverse sweeps. Again, be sure all boards are visible, fill the screen with as much liver parenchyma as possible and attempt to maintain the transducer so that the liver is perpendicular to the sound beam to allow for optimal b-mode resolution. Documentation can include a sagittal image of the left lobe at the IVC, aorta and lateral to the aorta. The next step is to sweep through the right lobe. Equipment settings must be optimized because the right lobe is larger and lies deeper in the abdomen. Depth should be increased so that there is approximately 2-3cm of space posterior to the most posterior right lobe border. The focus should be positioned in the posterior aspect of the right lobe. Once the equipment is optimized, the right lobe can be evaluated in the transverse and sagittal planes in a similar fashion as described for the left lobe. Be sure as much liver tissues as possible is visible and that all borders are visible. Sometimes in the right lobe it will be necessary to obtain images from an intercostal position rather than an anterior abdominal approach. Evaluation of the liver parenchyma can be accomplished in either imaging window and the window that best suits the patient should be used. Sample images could include transverse right lobe with hepatic veins, right portal vein, gall bladder and right kidney. Sample sagittal images can include right liver lobe with the right portal vein, gall bladder, right kidney and lateral to the right kidney. In addition to the documented images, be sure to sweep completely in and out of the liver parenchyma to be able to identify intrahepatic and extrahepatic structures. Some of the described sample images can be viewed by watching video #1 titled ‘Sample liver b-mode Images’. Any area that appears as a mass should be documented in 3 imaging planes with and without measurements including length, width and height. Notation should be made of the mass location compared to normal anatomic structures and color and power Doppler should be used to document the presence or absence of flow within the mass. The spleen also needs to be evaluated for echogenicity and overall size. It can be evaluated in the same methodical sweeping fashion as the liver with 2-3 representative images obtained in transverse and sagittal or coronal planes. It should show homogeneous echo texture, similar to the liver however, slightly less echogenic. The diaphragm should be visualized as a bright echogenic splenic border. The spleen is considered somewhat enlarged when its longitudinal axis measures >13cm. Some common findings of liver pathology may include lobulated liver surface with ascites, increased overall echogenicity or hypertrophy of the caudate lobe and decreased right liver lobe size.

Video 1. Realtime imaging illustrating liver anatomy.

Once finished with the overall assessment of the liver in b-mode, all liver vasculature should be identified with color and spectral Doppler to confirm their presence, patency and direction of flow. These three things should be observed for all hepatic veins, the inferior vena cava, the main, right and left portal veins, the splenic and superior mesenteric veins, and the splenic and hepatic arteries. The liver and splenic vasculature can be imaged from either the intercostal and subcostal approaches. The main portal vein should be identified as it crosses anterior to the inferior vena cava. A slight oblique scan plane will often show the portal vein in its longest axis. During quiet respiration, the portal vein diameter is measured in b-mode as it passes anteriorly to the inferior vena cava and should not exceed 13mm. Respiration will also affect portal vein diameter and the caliber of the portal vein may change drastically with sustained deep respiration. Some reports describe that the splenic and superior mesenteric veins

may also increase by 50 or even 100% from quiet to deep respiration. The ultrasound beam should be perpendicular to the walls of the vessel to achieve maximum spatial resolution. Portal vein diameter >13mm is diagnostic for portal hypertension with a high specificity. Image 1 demonstrates the correct main portal vein positioning for diameter measurements.

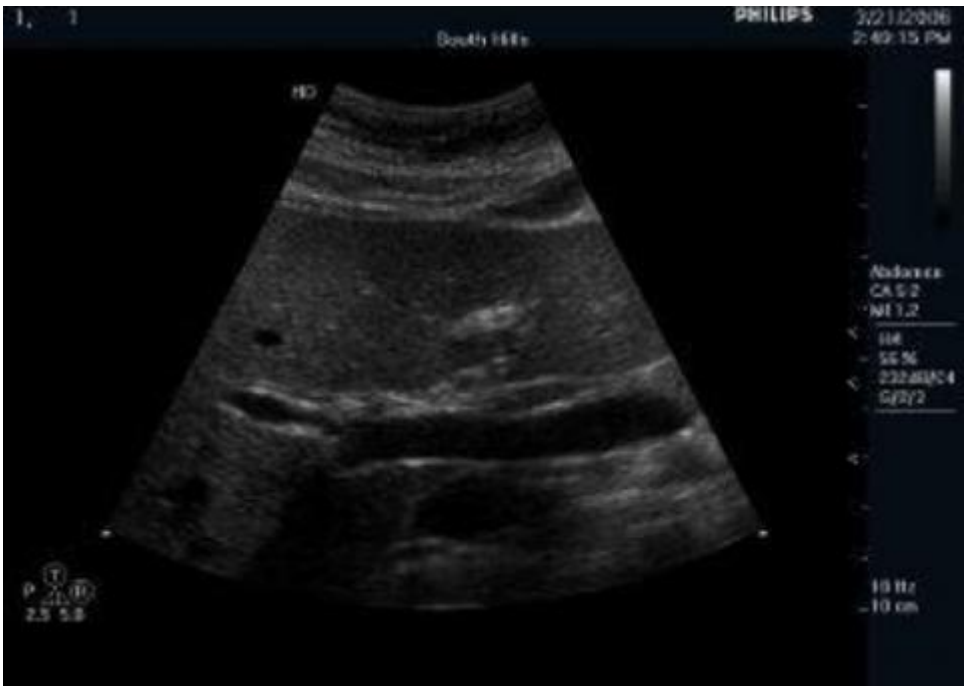

Image 1. Correct main portal vein positioning for diameter measurements.

Interrogation of the portal vein should be performed with the portal vein in its longest axis. To achieve a correct insonation angle, slide the transducer to the intercostal or subcostal location and tilt the sound beam so that it is directed back toward the portal vein as shown in image 2. The right and left branches of the portal vein are also insonated from this intercostal view and they must be interrogated throughout their course to identify their flow direction. Normal flow within the portal vein should be toward the liver, hepatopetal, throughout the cardiac cycle. Hepato is Latin for liver and petal is Latin for toward. Several authors report a normal portal vein velocity range of 15-18cm/s. This can vary significantly with respiration and cardiac activity. Portal venous flow may show subtle phasic variations associated with the thoracic pressure changes during normal breathing. This can also be observed from the spectral display shown in image 2. The splenic and superior mesenteric veins should exhibit similar flow characteristics to that of the portal vein. Flow should be hepatopetal and have slight respiratory variations. Incorrect identification of flow direction in the portal system is a pitfall of Doppler ultrasound assessment. This can be avoided by confirming flow direction from several transducer positions. Under abnormal situations, such as right heart failure or fluid overload, the right atrial pressure increases and the atrial pulsations can be transmitted through the liver and to the portal vein and flow will appear more pulsatile. Portal venous flow is also affected by the body’s response to ingestion of a meal. In a post-prandial state, there is increased supply of oxygenated blood to the intestines to facilitate digestion. The visceral vessels will dilate and increase the blood flow. The hepatic artery exhibits the opposite response after a meal. Blood flow in the hepatic artery decreases probably due to vasoconstriction.

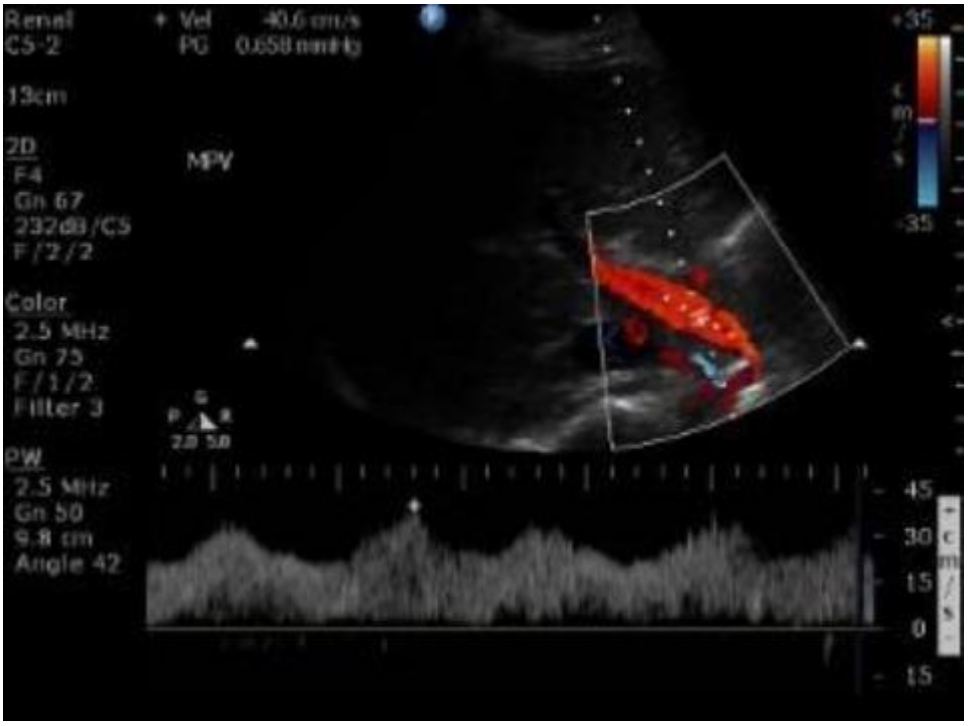

Image 2. Correct angle for Doppler interrogation of the portal vein.

The hepatic veins can be found using a transverse sub-xiphoid view angling cephalad to identify the confluence of the hepatic veins with the inferior vena cava. As shown in image 3, you should see the three vessels converging with the inferior vena cava. Normal hepatic veins should be

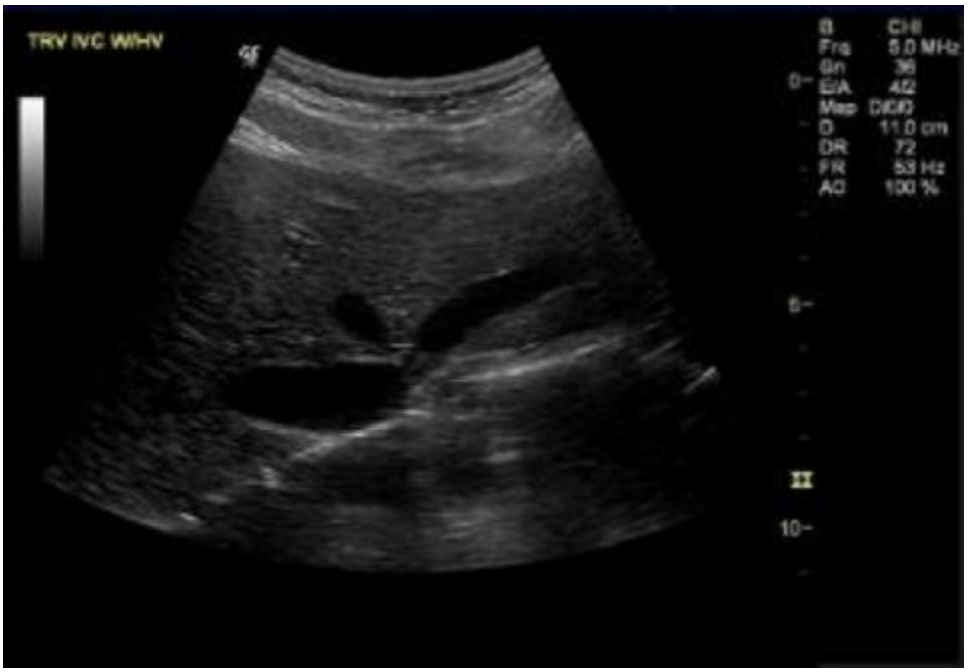

Image 3. Cross section of the IVC at the confluence of the three hepatic veins.

anechoic with thin walls, surrounded by liver parenchyma. As previously described, the portal veins have thick echogenic walls while the hepatic veins are thin walled making their appearance sonographically invisible. Hepatic vein Doppler signals should be pulsatile due to the transmission of arterial pulsations from the right atrium of the heart. There should also be changes in the waveform due to respiratory variations. Under normal circumstances, the majority of the flow should be hepatofugal, or away from the

transducer as shown in image 4. The sub-xiphoid window works well for the mid and left hepatic veins; however, it is often difficult to

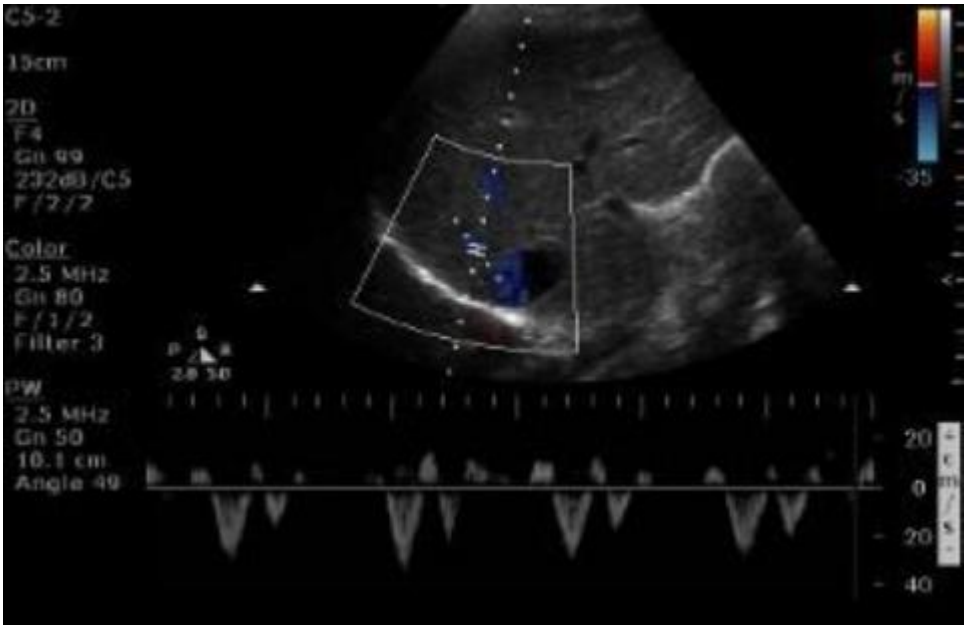

Image 4. Flow in hepatic vein moving away from the transducer

obtain a proper insonation angle for the right hepatic vein because it courses nearly perpendicular to the ultrasound beam. An intercostal position will often provide a proper insonation angle for the right hepatic vein as well as the proximal inferior vena cava. This position is shown in image 5. The mid and distal segments of the inferior vena cava can be evaluated from a midline or mid abdominal. The distal IVC Doppler signals will be less pulsatile than the proximal IVC because it is farther away from the cardiac influence. Flow should be spontaneous, vary slightly with respiration, and be non-pulsatile.

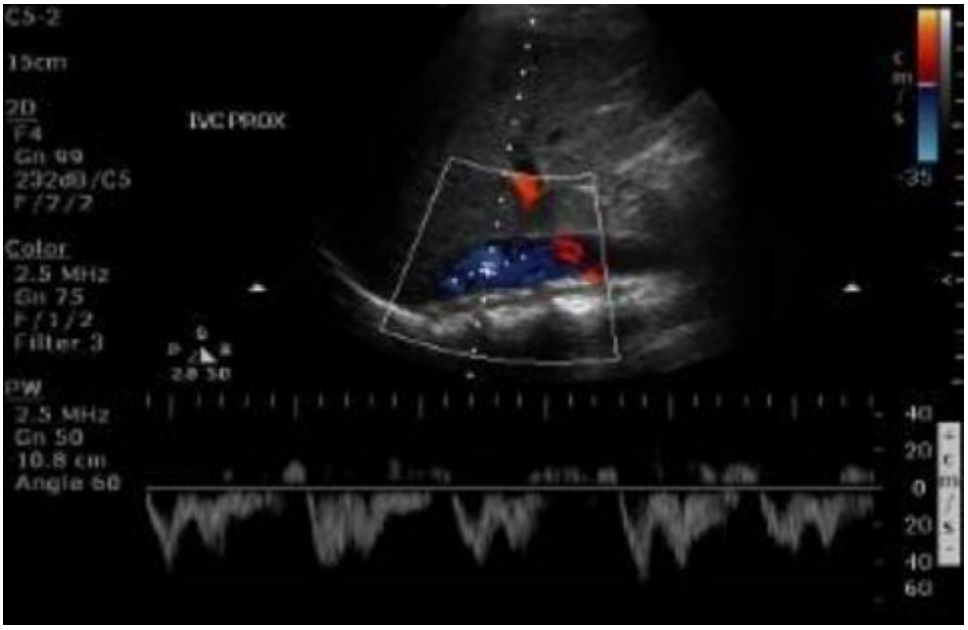

Image 5. Right hepatic vein as seen through an intercostal position

Hepatic and splenic artery evaluation is also performed for a liver duplex exam. The hepatic artery can be identified from the transverse anterior abdominal approach. Identify the origin of the celiac artery from the aorta in a transverse scan plane and observe the hepatic artery coursing laterally toward the

liver. Once the gastroduodenal artery branches inferiorly, the common hepatic changes its name to the proper hepatic artery to course toward the portahepatis. It then moves into the liver and branches into right and left channels. Doppler assessment should be hepatopetal and show continuous forward diastolic flow throughout systole and diastole, or a low resistance signal. The hepatic artery is sometimes tortuous and can occasionally be difficult to follow. The splenic artery can be identified also branching from the celiac but coursing laterally toward the spleen. It is rarely followed to the splenic hilum from the anterior approach due to its tortuosity. Insonation of the distal splenic artery should be performed from the left lateral approach. Image 6 shows a normal spectral Doppler waveform of the hepatic artery demonstrating a low resistance flow pattern that is typical for either the hepatic or splenic arteries.

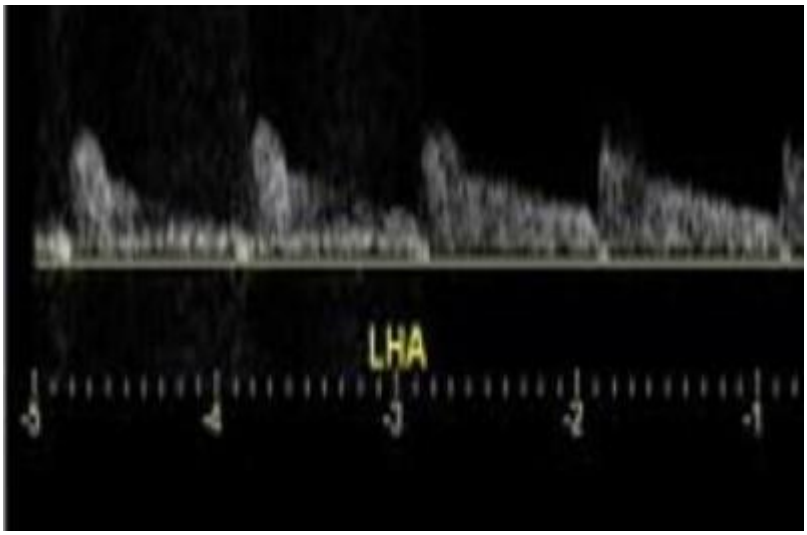

Image 6. Low resistive waveform in the hepatic artery

Minimum documentation for a liver duplex should include spectral Doppler signals of the following locations:

- Main portal vein (extra and intrahepatic), right and left portal veins
- Splenic vein
- Superior mesenteric vein
- Right, middle and left hepatic veins
- Proximal, middle and distal inferior vena cava
- Proximal, middle and distal hepatic artery
- Proximal, middle and distal splenic artery

One last component of the duplex exam will be determining the presence or absence of portosystemic collaterals. Collaterals should be suspected if the portal vein diameter is more than 13 mm; portal flow is oscillating or retrograde; there is splenomegaly or ascites. Those would all be indications of portal hypertension and the patient would be at increased risk of collaterals and bleeding. Collaterals develop from necessity because the blood must return to the heart, but the normal path through the liver is restricted so they serve to help decompress the system. The most common available collateral pathway is the umbilical vein, which originates from the left portal vein. In the presence of a patent umbilical, flow may remain hepatopetal throughout the left portal, splenic and superior mesenteric veins but the right portal vein may become hepatofugal. The umbilical vein courses in the liver with the ligamentum teres.

The coronary vein is also a potential collateral pathway. It can be identified as it runs parallel to the superior mesenteric vein. It joins the splenic vein from a superior position and is considered abnormal if flow is retrograde or if the diameter is >4mm. Some authors report that retrograde flow in the coronary vein occurs in 90% of patients with portal hypertension. The increase pressure in this vessel will result in esophageal varices. Another potential collateral pathway is a splenorenal shunt. There will be hepatofugal flow in the portal system and in the splenic vein and then the flow will be shunted into the left renal vein to empty into the IVC. These collaterals that develop will also be associated with multiple gastric, splenic and esophogeal varices.

If evaluating the liver post-transplantation, the main role of Doppler ultrasound is to evaluate the patency of the anastomoses created surgically of the portal vein and the hepatic artery. Initial post-operative evaluation is often difficult due to surgical dressings, abdominal gas and drainage tubes. The basic information obtained in a standard liver Doppler examination can be used for evaluation in the post-operative liver transplantation. The liver parenchyma can be evaluated using gray-scale as described previously with close attention to perihepatic and intrahepatic fluid collections. Intrahepatic fluid collections especially near the portahepatis should be evaluated with color Doppler to differentiate fluid from the portal vein or the hepatic artery which may be aneurysmal. Flow quality, direction and velocity should be recorded throughout the main, right and left portal veins, and the splenic and superior mesenteric veins. Discrepancies in portal vein diameter between donor and recipient may exist and velocity information from those areas is important to take note of. Kinking at an anastomosis is also a possibility and may cause increased velocities to be present. One of the other most common reported complications is stenosis or occlusion of the hepatic artery. Early occlusion of these vessels usually results in loss of the transplant if revascularization is not performed in time. Intrahepatic arterial signals that are normal may be useful as indirect evidence that there is good flow within the transplanted hepatic artery. Hepatic artery flow in the initial post-operative period may be high resistance but by the end of the first week, the resistance decreases to more normal levels. When high resistance is sustained or a resistive index of greater than 0.7 exists for more than the first week, this may suggest pending liver transplant rejection. The hepatic veins and inferior vena cava are also assessed for patency looking for thrombosis or anastomotic stenosis. The same flow patterns seen with a normal liver Doppler exam should be observed post-transplantation. Complications involving stenosis or thrombosis of the hepatic veins or inferior vena cava are rare.

INTERPRETATION

Abnormal findings for the Doppler component would include oscillating or hepatofugal flow in the main, right or left portal veins, splenic vein or superior mesenteric vein. An enlarged portal vein diameter >13mm is a sign of portal hypertension. B-mode evaluation should also include assessment for thrombosis in the portal, hepatic, splenic, superior mesenteric veins or the IVC. Acute thrombosis would appear as hypoechoic echoes visualized within the lumen of the vessel and with reduced or absent flow by spectral Doppler. Chronic thrombosis would appear as echogenic material within the vessel lumen and a contracted vein. Multiple collaterals are often present to shunt the blood around the vessel. These multiple, tortuous collateral vessels are referred to as cavernous transformation and take many years to form. If echogenic material is present in the lumen of the portal vein, it could also be the result of a malignant thrombus. This could occur from hepatocellular carcinoma with vascular invasion. A patent umbilical vein with hepatofugal flow is seen in the majority of patients with portal hypertension and is the most common collateral pathway. Gastroesophogeal, varices, and splenorenal collaterals are all signs of

portal hypertension as well as splenomegaly, which is defined as spleen measuring > 13cm. Correct identification of gastroesophogeal varices is extremely important for this examination due to their potential risk of rupture. Death can result if bleeding is not contained. Gastroesophogeal varices can be identified by locating the diaphragm near the aorta. The diaphragm will appear as an echogenic structure. Image in a sagittal plane near the aorta with color Doppler and look for dilated serpiginous vessels underneath the diaphragm and above the stomach. Abnormal findings for the hepatic and splenic artery signals would include high resistance flow patterns that indicate parenchymal disease. There could also be arterial stenosis where there is a focal increase in peak velocities, post-stenotic turbulence and a tardus parvus signal. Signs of Budd-Chiari syndrome would include decreased pulsatility reversed or absent flow in the hepatic veins or IVC. Echogenic material in the vessel lumen could indicate thrombosis or tumor invasion.

CONCLUSION

In summary, the liver Doppler examination is a valuable tool for assessment of the portohepatic circulation. The liver vasculature can be readily seen on ultrasound in a high percentage of patients and the exam can yield accurate and reproducible information. A liver duplex examination can assist physicians in the diagnosis and treatment of portal hypertension, intrahepatic portosystemic shunts, portal vein or hepatic vein occlusion. This online course has covered the normal anatomy and physiology of the liver, how to systematically assess the liver and its vasculature by ultrasound, how to assess the collateral circulation, and understand the ultrasound findings associated with common liver diseases. This examination can be a great diagnostic tool in helping clinicians properly diagnose and treat vascular disorders of the liver.

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