IMAGING THE HEPATIC LYMPHATICS: EXPERIMENTAL STUDIES IN SWINE

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Magnetic resonance (MR) imaging augmented with 3-D MR reconstruction provides an excellent display of the soft tissues and surface anatomy of the human body. The excellent anatomical detail of MR images makes this radiographic modality an ideal tool to teach anatomy to all health-care professionals.

Previous studies of the lung and liver in swine revealed that the hepatic lymphatics communicated with the visceral pleural lymphatics via the so-called pulmonary ligament, which appears as a sheet of visceral pleura containing lymphatics and small blood vessels in the swine model. A review of the surgical operative reports at the UCLA School of Medicine revealed that the hepatic lymphatics are not connected or even ligated during hepatic resections and transplantations. Therefore, the authors hypothesized that the unattached lymphatics may be a cause of postoperative complications and that interruption of these important lymphatic pathways may specifically result in immediate ascites and right pleural effusions. Cannulation of the hepatic lymphatics is proposed as a method to reduce postoperative complications.

The purpose of this research is to demonstrate the visual and radiographic display of the hepatic lymphatics in a swine model and to provide a means to teach anatomical-pathological correlation. (*J Natl Med Assoc.* 1993;85:185-191.)

Key words • magnetic resonance imaging (MRI) • Ethiodol oil • swine liver • transplantation • lymphatics

Traditionally, the radiologist has used plain films, intravascular contrast agents, and radiopharmaceuticals to image the liver. Hepatic lymphatics have been accidentally imaged during percutaneous transhepatic cholangiograms. They appeared on the fluoroscopic screen as small, linear, slowly emptying structures paralleling larger veins. These lymphatics seemed to have no apparent communication or definite anatomic pathways. Because the hepatic lymphatics have not been studied extensively, the importance of these structures has remained a curiosity to the anatomist, pathologist, and inquisitive radiologist who occasionally imaged them.

With the advent of computerized radiographic imaging (computerized tomography [CT], ultrasonography, magnetic resonance imaging [MRI], 3-D reconstruction, cine-MR, and SPECT nuclear medicine), there has been a virtual explosion of methods for the radiologist to image the liver in a noninvasive fashion. We have used MRI to study the lymphatics of the lung and the liver in a swine model.[1,2] In these previous reports, we observed that the hepatic lymphatics communicated with the visceral pleural lymphatics via the so-called pulmonary ligament, which appears as a sheet of visceral pleura containing lymphatics and small blood vessels in the swine model. This observation was confirmed by the senior author (JDC) during his participation at many human autopsies. Moreover, dilated lymphatics in liver transplantation and cancer

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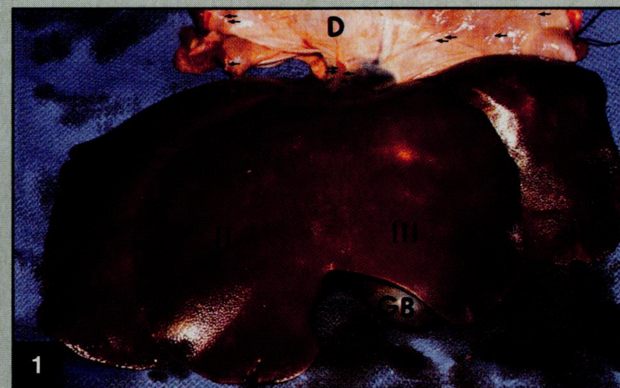
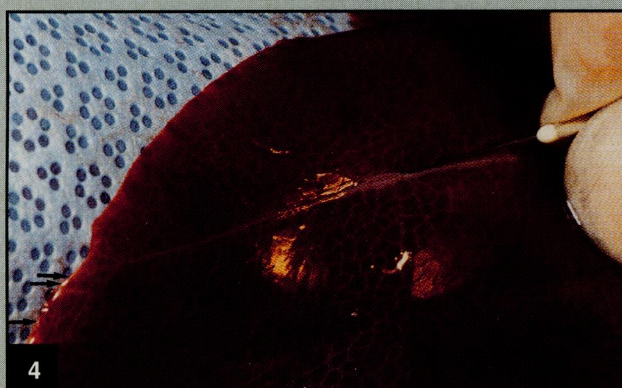




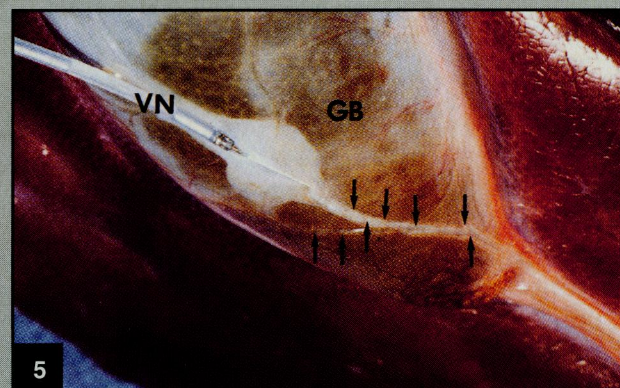


Figure 1. The gross specimen of the swine liver demonstrating the four lobes (I, II, III, IV). Anastomosing lymphatics (arrows) and vascular structures are contiguous with the fascia and inferior surface of the diaphragm (GB = gallbladder and D = diaphragm). **Figure 2.** The visceral surface demonstrating fat radiating from the lobes of the liver. The lymphatics (arrows) anastomose with hepatic lobules (PH = portahepatis and LN = lymph node). **Figure 3.** One edge of the liver demonstrating the benzene-like structures of the hepatic lobules. Lymphatics (arrows) marginate the liver edge interdigitating with the hepatic lobules. **Figure 4.** A retrograde saline injection of a capsular lymphatic. Note the filling of the adjacent collateral lymphatics circumscribing the hepatic lobules. Marginal lymphatics are dilated (arrows). **Figure 5.** The saline injection into a large surface lymphatic (untied) of the gallbladder. Saline has extravasated around the needle. Note areas of constrictions (lymph valves). Vascular structures parallel the dilated transparent lymphatics (arrows) (GB = gallbladder and VN = Viamonte needle). **Figure 6.** Saline has been injected into visceral surface lymphatics (tied) to demonstrate collateralization (arrows) with the hepatic lobules and lymph nodes (GB = gallbladder). **Figure 7.** Radiograph demonstrating oily contrast injected into the capsular lymphatic of Figure 4. Interlobular and marginal lymphatics (arrows) are filled. Extravasation (arrow with crossbar) has occurred at the injection site (GB = gallbladder and PH = portahepatis).

patients have been demonstrated on CT images of the liver as low-density areas surrounding the intrahepatic bile ducts.[3]

We have cannulated swine lung lymphatics with small and large needles, injected contrast, and imaged these lymphatics with plain radiography, CT, and MRI. Therefore, it would seem logical that the hepatic lymphatics could be cannulated, contrast injected, and imaged by similar methods. We were successful in this endeavor.

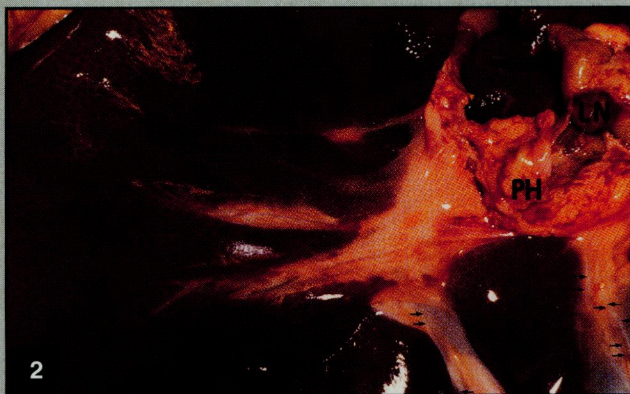
This article describes a hepatic lymphatic cannulation technique with radiographic images of the contrast injected swine liver model. We present this research to demonstrate a visual radiographic display of hepatic lymphatic pathways using various radiographic modalities and to provide a model that may be used to teach anatomical-pathological correlation to health-care professionals.

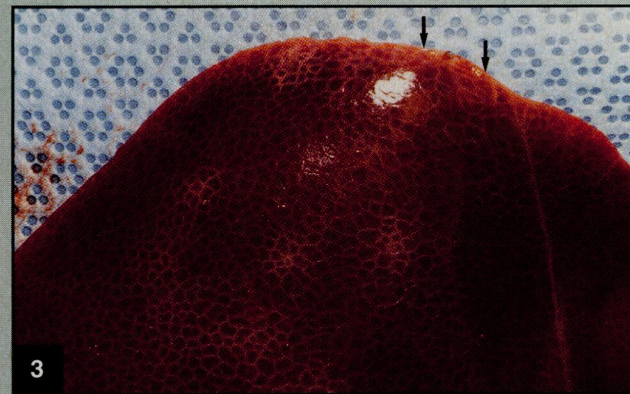
METHODS AND MATERIALS

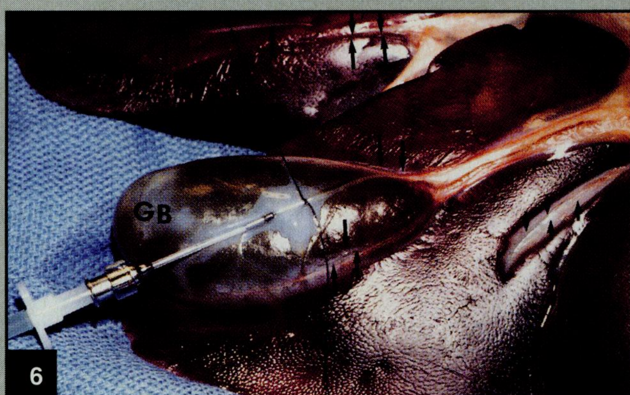
Fifteen adult Red Duroc swine (40 kg to 45 kg) were given preoperative ketamine and lidocaine before being placed on the fluoroscopic table. An 8-mm endotracheal tube was inserted proximal to the division of the trachea under fluoroscopic control. The tube was secured by inflating the endotracheal cuff. An Ohio ventilator (Ohio Medical Products, a Division of Airco Inc, Madison, Wisconsin) was used to administer halothane for general anesthesia.

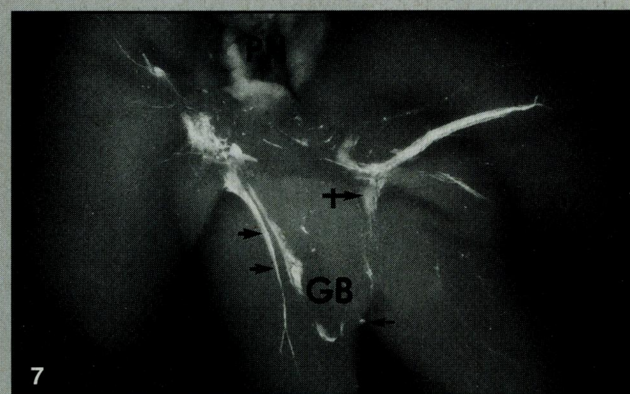
A vertical incision was then made from the level of the thyroid cartilage to approximately 25 cm below the xyphoid process. Blunt dissection was performed down to the fascial planes of the neck, mediastinum, and the upper abdomen. The major blood vessels of the neck, thorax, and upper abdomen were tied off with 4.0 silk ligatures in order to maintain a clear field of vision to harvest the lungs, heart, and liver. The esophagus and the thoracic duct also were tied off with 4.0 silk. The inferior visceral pleural reflection from the pulmonary hila to the diaphragm was preserved along with the diaphragm. This was accomplished to maintain the lymphatic drainage from the abdomen and the diaphragm. The lungs, heart, and liver were then harvested, and the swine were killed with an intravenous injection of phenobarbital and exsanguination.

The liver and diaphragms were separated from the









lungs. The inferior vena cava, aorta, and portal vein were tied off to keep the lymphatic drainage intact. A 31-ga needle was inserted into the lymphatics along the edge of the liver margin, liver capsule, gallbladder, and the portal vein. A 10-mL syringe was used to hand inject saline and Ethiodol oil (Savage Laboratories, Melville, New York) into the lymphatics of the liver. This same technique was used by the senior author (JDC) on the resected bowel of four adult white rats and rabbits to determine the time for anastomosis of the severed lymphatics in small bowel transplantation experiments.

Normal saline was injected selectively into the marginal lymphatics to identify the largest lymph channels for cannulation. The capsular, marginal, gallbladder, and portal vein lymphatics were cannulated. The needles were then connected with K-50 tubing to a 20-cc plastic syringe. The Ethiodol oil was infused by hand. Overhead and spot fluoroscopic films were obtained using a Phillips radiographic fluoroscopic unit (Phillips Medical Systems, Hamburg, Germany). A Picker P-Q 2000 (Picker International, Cleveland, Ohio) scanner was used to obtain the transverse (axial) CT images. A multiplane reconstruction program was used to obtain the sagittal and coronal CT images. The liver was placed into a cardboard box to secure it in a fixed position. The box was inserted into the CT gantry and oriented to obtain the coronal and sagittal images.

A 1.5 Telsa GE Signa MRI unit (GE Medical Systems, Milwaukee, Wisconsin) was used to obtain T1-weighted coronal and transverse images. Three dimensional reconstructed color images were provided by ISG Technologies (ISG Technologies Inc, Mississauga, Ontario, Canada). Four bags of 500 mL normal saline solution were placed beneath the fresh liver specimen to enhance the image quality. Ektachrome 100 daylight film was used to obtain color slides for the figures.

RESULTS

The heart, lungs, and liver were harvested from 15 swine within 20 minutes following euthanasia. The surface of the lungs were very red from the pooling of blood in the capillary bed. The harvested liver was not discolored (Figure 1). The glistening lymphatics of the

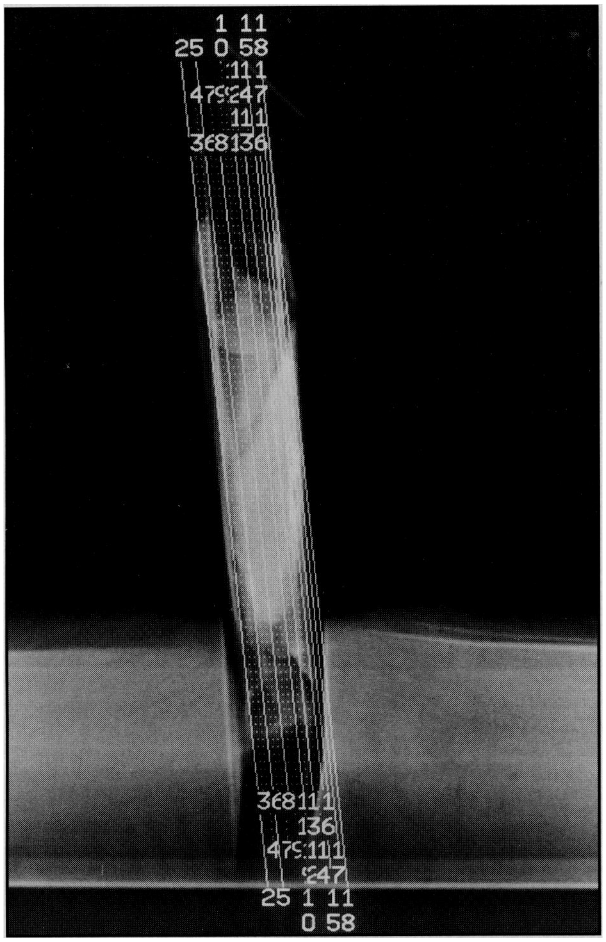


Figure 8. A 2-D reconstructed CT image of the swine liver in a cardboard box demonstrating the cursor lines numbering the coronal images.

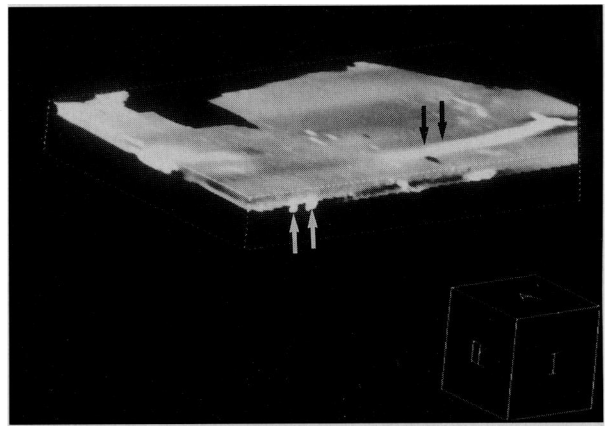


Figure 9. A 2-D reconstructed CT image of the swine liver in the coronal plane. Intrahepatic and interlobular lymphatics are filled with oily contrast (white arrows). Capsular lymphatics are indicated by the black arrows.

liver, gallbladder, portal vein (Figure 2), and inferior cava were observed as was the visceral pleural lymphatics of the lung. The multiple benzene-like structures of the hepatic lobules were clearly identified on the liver surface (Figure 3).

Retrograde saline injections into the marginal and capsular lymphatics over the liver surface demonstrated the collateral lymphatics along the liver edge (Figure 4). The needles were introduced but not secured in the lymphatics over the liver surface because the lymphatics were contiguous with one surface of the liver (Figure 5). The injection (antegrade) into the surface lymphatics of the gallbladder dilated and demonstrated intrahepatic collateral lymphatics and lymphatics marginating the portal vein (Figures 5, 6, and 7). The surgical dissecting scope confirmed the narrowed constricted areas as valves in the lymphatics draining the gallbladder. The surface lymphatics dilated at the tip of the needle from 1 mm to 1.5 mm (Figure 5). The saline injections allowed our team to select several lymphatics for cannulation. Saline extravasated at the injection sites of the untied lymphatics. The large surface lymphatics of the gallbladder were dissected free of the gallbladder, and the inserted needle was tied in place easily. The cannulation of the lymphatics along the liver edge and the portal vein proved to be the most difficult because the needles were larger than the lymphatics.

The injection of Ethiodol was difficult because the viscosity of the oil added to the opposing pressure of the smaller intrahepatic and marginal lymphatics. The continued contrast injections in the capsular lymphatics demonstrated contrast at the surface of the liver and in the lymphatics marginating the inferior vena cava, portal vein, and the gallbladder (Figure 7). Computerized tomographic coronal and 2-D reconstruction images documented collateral flow between the smooth surface capsular lymphatics, intrahepatic, and visceral interlobular lymphatics (Figures 8 and 9). Magnetic resonance images and plain radiographs confirmed the saline and contrast injections. The reconstructed 2-D CT (Figures 8 and 9) and 3-D MR images (Figures 10 and 11) best demonstrated collateral circulation between the visceral (smooth) surface lymphatics and the interlobular lymphatics (Figures 5 and 6). Magnetic resonance imaging documented the oily contrast in the periportal lymphatics and not within the hepatic veins.

DISCUSSION

A knowledge of the hepatic anatomy is mandatory

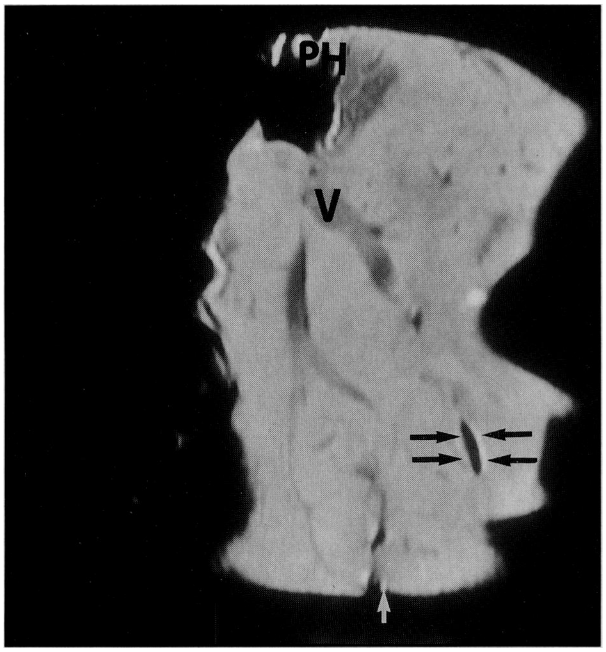


Figure 10. A coronal MR image demonstrating the periportal lymphatics (black arrows), marginal lymphatics (white arrow), portahepatis (PH), and hepatic veins (V).

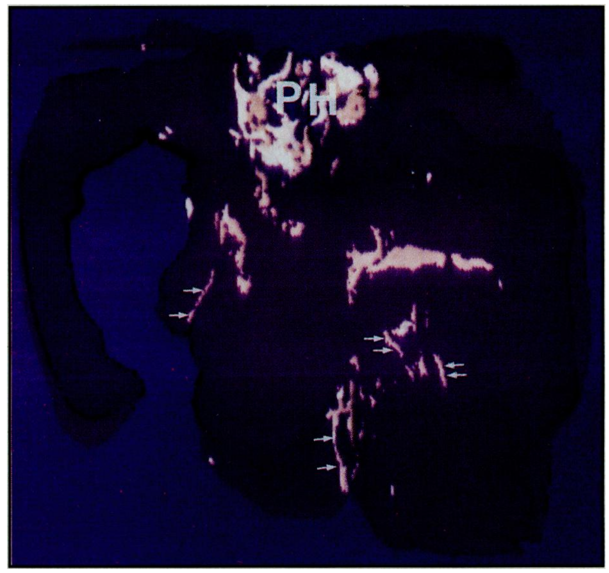


Figure 11. A 3-D reconstructed transparent color MR image of the liver demonstrating the overlay filling of many intrahepatic lymphatics. Oily contrast exits from the cut lymphatics at the portahepatis (PH). Periportal and interlobular lymphatics are indicated by the arrows.

for the performance of liver transplantation. The vascular anatomy of the liver has been reviewed extensively in anatomy textbooks and in scientific articles.[4] However, the anatomy of the hepatic and adjacent lymphatics has not been extensively researched for purposes of improving transplantation.

A literature search did not reveal any articles on the visual and direct cannulation of the surface lymphatics of the liver. However, collateral lymph circulation can be demonstrated and does occur in the upper and lower extremities.[5] Collateral circulation does exist within the liver and the lung and has been demonstrated by such authors as Burgener et al[6] in 1977, Deimer[7] in 1983, Itoi et al[8] in 1988, and Collins et al[1] in 1991. The lymphatics of the liver and the lung can be cannulated with large-bore modified Viamonte 18-ga blunt tip needles. The surface lung and hepatic lymphatic anatomy in swine and human lymphatics have a similar distribution. The imaging of the liver and lung lymphatics in the swine model is currently being used to further the teaching of anatomy to residents in radiology and at autopsy rounds in pathology.[1]

Plain radiography, CT, and MRI can demonstrate the communication of the contrast-filled liver lymphatics within the portahepatis. Computerized tomography demonstrates contrast in the intrahepatic collateral lymphatics, and the 2-D reconstructed CT images best define periportal and perivascular lymphatic collateral communication. Therefore, the ligamentous attachments of the liver become very important in performing liver resections and transplantations.

Briefly, the human liver has four segments and the swine liver has four lobes. The larger human liver is connected to the undersurface of the diaphragm and to the anterior wall of the abdomen by five ligaments. Four of these are peritoneal folds (falciform, coronary, and two triangular lateral ligaments). The fifth is the round ligament (the fibrous cord of the obliterated umbilical vein). Within these ligamentous fascia planes and connective tissue are lymphatics, small blood vessels, and nerves. The human liver is further fixed in the abdomen by the ligaments, connective tissue, inferior vena cava, and the hepatic veins. The falciform ligament does not contribute to the support of the liver.[7] Our dissections of the swine liver reveal that the right dome of the liver is connected by a thin circular ligament (containing lymphatics, veins, and capillaries). Further communication with the diaphragm is established at the inferior vena cava hiatus, portahepatis (Figure 1), and the surrounding peritoneal folds of the adjacent bowel and vascular structures. Swine lymphatics also anastomose the undersurface of the diaphragm

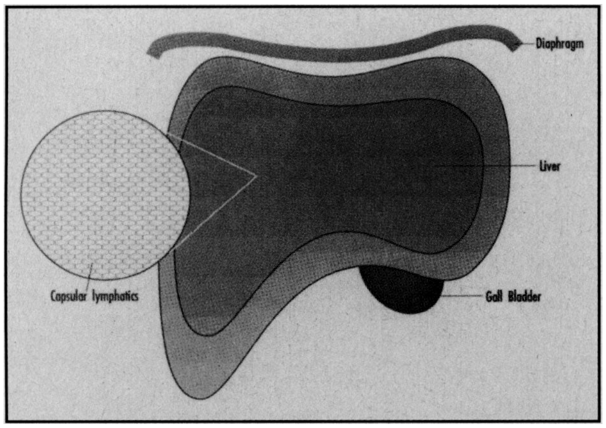


Figure 12. Drawing of the swine liver as it appears grossly after harvesting. The smooth dorsal surface is anterior, and the right lobe of the liver is on the right. The liver is not attached to the dome of the diaphragm. The capsular lymphatics are seen enlarged within the circle.

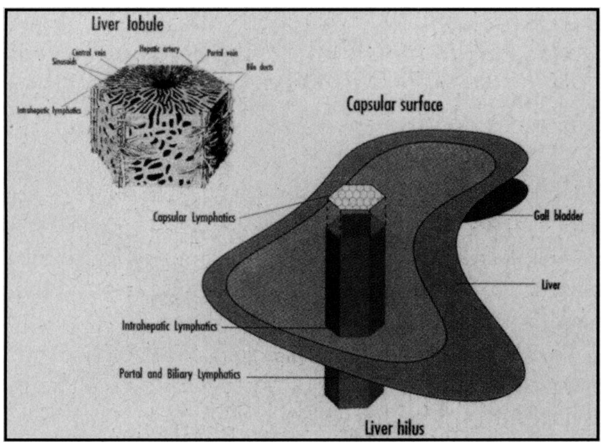


Figure 13. Drawing of the swine liver demonstrating the 3-D appearance of the capsular lymphatics communicating with surface, marginal, portal, biliary, and hilar lymphatics. The polygonal hepatic lobule is enlarged in the upper left corner.

to the hepatic veins and the inferior vena cava.

The review of our surgical operative reports indicate that the lymphatics are not tied or stented in liver and lung resections or cardiac transplantations. Large right pleural effusions and ascites are common postoperative complications in liver transplantations and are routinely demonstrated on the postoperative upright chest and abdominal radiographs. When the liver is removed from the recipient, the lymphatics are transected and not ligated. The transplanted liver is secured to the recipient's vascular supply and intestinal attachments.

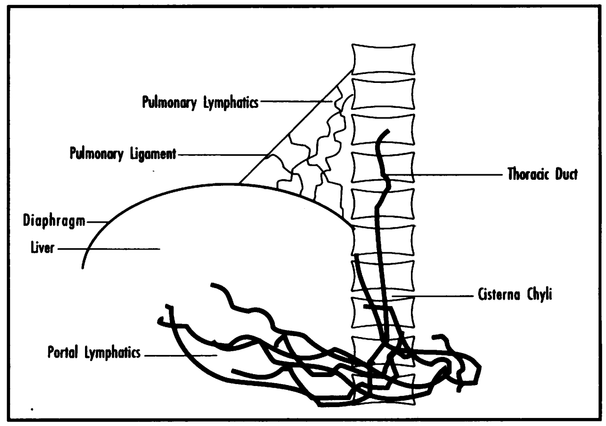


Figure 14. Diagram demonstrating the communication between the liver, abdomen, diaphragm, and lung. The portal lymphatics anastomose within the liver. The pulmonary lymphatics in the pulmonary ligament are contiguous with the diaphragm via the visceral pleura.

The lymphatics remain unattached. The severed lymphatics connecting the liver to the visceral surface of the diaphragm and visceral pleura of the lung are free to deposit lymph. The lymph leaks from the unattached lymphatics resulting in postoperative pleural effusions, ascites, and loss of electrolytes. This has led to postoperative accumulation of free fluid interfering with lung aeration and pneumonias because the lymphatics had been overlooked intraoperatively.

Surgery performed on large adult rats and white rabbits by the senior author (JDC) determined that the lymphatics were fully reunited without cannulation in 10 to 14 days postsurgery. The injection of oily contrast (Ethiodol) documented that the lymphatics were intact. It would seem logical that stenting or anastomosing some of the major hepatic lymphatics would reduce postoperative complications.

The surface or capsular lymphatics of the swine liver (Figures 3 and 4) communicate with the polygonal hepatic lobules and appear as continuous strands of benzene ring (Figure 12). The lymphatics intercommunicate with marginal surface lymphatics as collaterals leading to an elevator shaft in a tall building (Figure 13).' They anastomose with the portal, biliary, and hepatic vein lymphatics (Figures 13 and 14).

The studies by Deimer[7] illustrated the communication of the surface lymphatics (marginal) with intrahepatic lymphatics (Figures 13 and 14). We were not able to document extravasation of lymph from a stroma as suggested by Deimer.[7] We did observe collateral filling of the lymphatics of the diaphragm communicating with the lungs. Figure 14 is a modified diagram from a study by Deimer that demonstrates the communication of the portal lymphatics within the liver.[7] The human and swine liver lymphatics anastomose with the lymphatics of the inferior cava, diaphragm, lung, and thoracic duct. In the swine, the pulmonary lymphatics anastomose at the superior aspect of the diaphragm by a circular ligament as described and as the inferior vena cava enters the thorax.

Autopsies on liver transplant patients at our institution demonstrate passively congested enlarged livers. The capsular (surface) lymphatics and marginal lymphatics are dilated and grossly visible. Swabbing the liver surface with methylene blue selectively identifies the dilated lymphatics. Obstruction of the lymphatics does not allow normal lymph flow from the hepatic lobule into the portal triad. It is reasonable to assume that the same metaplastic changes occur in the liver when the lymphatic drainage is not reestablished. Collateral lymphatic circulation is able to drain some hepatic lymphatics (circumvention) in cases of injury to liver cords. However, if there are no established sizable lymphatics to drain the hepatic lobule, the common bile duct and hepatic veins can only accommodate lymph drainage for a given time. Because the gallbladder is removed at liver transplantation, the largest lymphatic over the gallbladder could be selected for a stent or tubing, which may assist in the reduction of the edematous changes often accompanying transplantation. We intend to pursue our research to evaluate this hypothesis.

Acknowledgment

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Literature Cited

1. Collins JD, Shaver ML, Disher AC, Batra P, Brown K, Miller TQ. Imaging the thoracic lymphatics: experimental studies of swine. *Clinical Anatomy.* 1991;4:443-446.
2. Collins JD, Disher AC, Shaver ML, Miller TQ. Anatomy of the lymphatic drainage of the liver as displayed by the plain x-ray and magnetic resonance imaging. *Anat Rec.* 1991;228:17A. Abstract.
3. Koslin DB, Stanley RT, Berland LL, Shin MS, Dalton SC. Hepatic perivascular lymphedema: CT appearance. *AJR Am J Roentgenol.* 1988;150:111-113.
4. Ger R. Surgical anatomy of hepatic venous system. *Clinical Anatomy.* 1988;1:15-22.
5. Collins JD, Bassett LW, Snow H, Ross NA, Patin T. False positive thromboscintigram resulting from lymphedema: a roentgen pathological model. *J Natl Med Assoc.* 1986;78:875-881.
6. Burgener FA, Webber DA, Kormano M. Hepatography and liver lymphography by retrograde biliary ethiodol infusion: an experimental study in the dog. *Invest Radiol.* 1977;12:259-266.
7. Deimer EE. *Clinical Radiology of the Liver.* New York, NY: Dekker; 1983.
8. Itoh T, Kanaoka M, Obara A, Furuta M, Itoh H. Lymphangiosis carcinomatosa of the liver. *Acta Pathol Jpn.* 1988;38:751-758.
9. Gray H, ed. *Anatomy of the Human Body.* 27th ed. Philadelphia, Pa: Lea & Febiger; 1959:1300-1301.