Computed Tomography of the Liver and Gall-bladder

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Radiological techniques have for decades been used in gallbladder and biliary disease with considerable success but their application to the liver has been much more recent. Gallstones can be shown on plain films; a relatively non-toxic contrast medium for the gallbladder was discovered some 40 years ago and even percutaneous hepatic cholangiography was described as early as 1937 by Huard and Do Xuan, whereas the liver remained a relatively blind region for radiological techniques. Parenchymal contrast agents proved illusive or, like thorotrust, too toxic, and for a while the demonstration of varices in the diagnosis of portal hypertension and calcified hydatid cysts was the most that radiology could offer[1].

A new era in radiodiagnosis of the liver began with the introduction of angiography, starting with splanopertography and hepatic venography and followed by selective arteriography. These techniques were used both in portal hypertension and in space-occupying lesions. By and large, malignant tumours were shown to be hypervascular, while benign tumours and cysts were avascular, although there were notable exceptions. The accurate localisation and diagnosis of smaller lesions remained a problem and, furthermore, angiography, though relatively safe, is nevertheless an invasive procedure.

The direct visualisation of the liver has now become possible with at least three non-invasive procedures; isotope scanning, ultrasonography, and computed tomography. While this article is concerned almost exclusively with computed tomography, comparison with the other techniques is inevitable, particularly if the respective clinical roles of these methods is to be attempted[2, 3].

Technology and Technique of Computed Tomography

Four distinct components are integrated to produce computed tomography: the scanner gantry that takes the readings, the computers that then process the data, the storage of the information and, finally, the apparatus for analysing and interrogating each examination.

The scanner gantry has an X-ray tube, with interlinked photon detectors on the opposite side of the body, which scans across or around the patient to take about 300,000 readings of tissue attenuation to produce each axial tomographic section. Each axial section is approximately 1 cm thick and with the common rotate/translate system takes 20 seconds to produce the readings. Hence, for movement-free scans the patient must stop breathing for 20 seconds, which can be a problem for the child, the dyspnoeic, and the elderly. Rotate scanning systems can, however, produce the 300,000 readings required for each section in 5 to 10 seconds[4].

The readings taken during each section are then processed by mini-computers using mathematical programs to calculate tissue attenuation values in each small area within the 1-cm thick section; subsequently these values are reprocessed to produce a picture of an axial section of the body. It is essential for the understanding of the clinical application of computed tomography to realise that the system produces tissue attenuation values that are subsequently converted into a picture, unlike conventional radiography which produces pictures.

Thus, tissue attenuation values can be used not only to produce a single picture but a whole range of pictures capable of showing bone, soft tissues or lung, and can be manipulated further for enlargement, subtraction techniques, reconstruction into coronal sections and statistical analysis.

The photograph of the computed tomography section is thus a highly edited version of the total data produced.

The data from each section is usually stored either on floppy disc or on magnetic tape. Each magnetic tape can hold up to 240 individual sections, which is usually sufficient for 12 to 20 patients.

The information on the magnetic tape is subsequently viewed on an independent viewing console that shows the anatomical sections on a television monitor and allows interactive interrogation of the data.

Preparation and Examination

With 18-20 second scan times each section must be done with breath-holding, and bowel movements must be prevented with Buscopan (N-butyl-hyoscine-bromide) or glucagon[5].

For the complete examination of the liver, sections would have to be done at 1-cm intervals, but in the vast
majority of cases the lesions being sought are larger than 2 cm and therefore sections at 2-3 cm intervals suffice, particularly as the examination is frequently completed by repeat sections after intravenous contrast enhancement with a urographic organic iodine contrast medium. Therefore, the examination of the liver may require 12 to 25 sections in the area from above the right diaphragm to below Reidel's lobe[6].

Contrast Enhancement of the Liver

Normal liver parenchyma has tissue attenuation values some 10-15 EMI units higher than adjacent structures such as the kidney, inferior vena cava, aorta or muscles, but is rather similar to spleen[7]. Some metastatic growths are not delineated unless the tissue attenuation of the normal liver parenchyma is considerably enhanced. At present, organic iodine compounds such as Hypaque or Conray are given intravenously in a dose equivalent to 40 g of iodine and raise the tissue attenuation values of liver by 20-25 EMI units. It would, however, be advantageous to have a contrast agent that would raise the tissue attenuation values of liver parenchyma by 40-50 EMI units and act for a somewhat longer time than a urographic contrast medium; such contrast agents may shortly be available[8] and intravenous glucose may also increase the tissue attenuation of the liver.

Axial Anatomy of the Liver

In the most cranial sections of the liver enclosed by the diaphragm there is surrounding lung with the heart lying adjacent to the right lobe of the liver. Subsequent sections show a crescent of pulmonary tissue posteriorly and lesions at the lung bases can be distinguished from intrahepatic lesions[9].

As a full thickness of the cranial part of the liver comes into view, the inferior vena cava and hepatic veins, enclosed by liver substance, become visible as lower density structures surrounded by liver parenchyma. The normal right lobe of the liver is closely applied to the inner wall of the upper abdomen except in the region of Reidel's lobe.

The portal vein and hilum also have a lower density than liver, with portal vein branches tapering towards the periphery or seen as rounded or ovoid lower densities (Fig. 1a, b).

The falciform ligament is usually obvious with its contained small rounded remnant of umbilical vein. The left lobe of the liver lies anteriorly adjacent to the anterior abdominal wall. The margin of the liver can usually be defined in thin individuals with no fat planes but is undoubtedly more clearly delineated in the obese[10].

Structures in the porta hepatis cannot usually be demarcated unless contrast medium is used but the normal gallbladder shows clearly, with tissue attenuation values far below that of the liver. Normal bile ducts are too small to be shown without contrast medium but, by using an oral cholecystographic agent, the right and left hepatic ducts can be delineated in relationship to the porta hepatis and the common bile duct followed in successive axial sections as it lies adjacent to the head of the pancreas (Fig. 1a, b). Air in the biliary system is also clearly visible (Fig. 2), particularly when it is dilated after choledocho-jejunostomy for obstructive jaundice. Normally the portal vein and its branches can only be seen on sections done within one minute of a bolus injection of intravenous urographic contrast medium[11].

Fig. 1. Computed tomography scan of the liver at the level of L1. The liver has a higher attenuation value than other abdominal organs, appearing much whiter. (A—aorta; K—kidney; Sp—spleen; St—stomach). (a) The ovoid trans radiancies are portal vein branches. The left hepatic bile duct (arrow) is shown after taking an oral cholecystographic agent. (b) The cystic duct and the common hepatic duct (arrow) lie adjacent to the duodenum and head of pancreas (P).
demarcated by surrounding fat, divides the liver into right and left lobes. In spite of these clearly defined landmarks an accurate estimation of liver size is extremely difficult. Only obvious enlargement or diminution in size of the whole or part of the liver can be recognised. The left lobe or right lobe of the liver may be absent or preferentially enlarged, producing a localised bulge that may mimic a tumour[12].

Splenic enlargement is more easily recognised and can readily be distinguished from other masses in the left hypochondrium (Fig. 3a), particularly after contrast enhancement.

The movement of the liver with respiration can lead to some difficulty in locating small lesions of 0.5-1.5 cm in diameter. It is certainly impossible to be sure of reproducing lesions of this size on follow-up examinations because with computed tomography only axial sections can be taken.

Parenchymal Liver Disease

At present computed tomography has only a limited place in the diagnosis of diffuse disease of the liver. Occasionally, marked nodular cirrhosis can be shown, and while splenomegaly in portal hypertension is immediately obvious, the associated distended collateral veins can cause paravertebral 'mass' effects (Fig. 3b), which must not be mistaken for lymphomatous lymphadenopathy or even paravertebral tuberculosis.

There are, however, two conditions that can produce almost pathognomonic appearances. Fatty infiltration of the liver produces markedly diminished tissue attenuation with unenhanced portal and hepatic veins

Size and Shape of the Liver

On axial sections the right lobe of the liver occupies most of the right half of the abdomen. The caudate lobe is immediately in front of the inferior vena cava, the liver hilum containing the portal vein, hepatic artery and bile duct is anterior and medial to the caudate lobe, and the anteriorly situated falciform ligament, often well

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Fig. 2. Air in bile ducts (arrowhead) not visible on a plain film of the upper abdomen adjacent to an abscess in the liver (arrow), postcholedochoduodenostomy.

Fig. 3. Upper abdominal and lower thoracic sections of a patient with portal hypertension due to liver cirrhosis. (a) Enlarged spleen (Sp), small right lobe of liver (Lr) and larger left lobe (Ll) with a cyst (C) of the right kidney (Rk). (b) Large 'mass' (white arrows) around the oesophagus (black arrow) and vertebral body caused by varices (A—aorta).
standing out in relief against the lower density liver substance (Fig. 4)[13]. A fatty liver also becomes much less dense than the spleen or the kidneys. Increased tissue attenuation of the liver occurs with haemochromatosis but is not as easily recognised as the fatty liver[14]. In haemochromatosis the lower density vascular structures are much more obvious than normal and the liver is much denser than the adjacent kidneys or muscles (Fig. 5).

In both fatty infiltration of the liver and haemachromatosis, computed tomography can be used to monitor treatment. It has been shown that by taking the same section at two different kilovoltages and with two different wedge corrections it is possible to estimate the iron content of the liver as accurately as by liver biopsy[15].

**Ascites, Loculated Effusions and Subphrenic Abscesses**

Ascitic fluid collects between the liver and spleen and the abdominal wall, producing a crescent of lowered tissue attenuation around the margins of the liver and spleen (Fig. 6). Loculated effusions can also occur, especially adjacent to the liver and are particularly associated with serosal metastases on the liver surface (Fig. 7)[16].

Ascites must be distinguished from pseudomyxoma peritonei and from infiltration due to colloid carcinoma of the ovary, colon or appendix. Although the mucoid tissue can also be interposed between the liver and abdominal wall it has a somewhat higher tissue attenuation.
than ascitic fluid and the displacement of the liver and spleen produces more of a straight margin (Fig. 8) than the even crescentic displacement of ascitic fluid.

Subphrenic abscesses occur more frequently on the right side adjacent to the liver than on the left but may even be bilateral (Fig. 9). A subphrenic abscess has tissue attenuation values considerably less than liver, which is obviously displaced by a low density region interposed between the liver and the lateral abdominal wall. The margin of the displaced liver is straightened and often 5-

Fig. 8. Liver (L) and spleen (Sp) displaced by colloid carcinomatous infiltration producing straightened margins of these organs (arrows). (A—aorta).

Fig. 9. Bilateral subphrenic abscesses (arrows) (L—liver; Sp—spleen; St—stomach; A—aorta).

10 cm long. While clinically it is not possible to distinguish a subphrenic from an intrahepatic abscess the appearances on computed tomography are quite different (Fig. 10).

Fig. 10. Abscess in the posterior aspect of the right lobe of the liver (segment 8) after contrast enhancement showing strands of tissue across the lesion. The tissue attenuation of the abscess is shown as 10 EMI units—(M + 10.0).

Extrahepatic Obstructive Jaundice

Dilated intrahepatic bile ducts produce multiple round or ovoid low density areas at the periphery of the liver and a linear branching pattern at the hilum, becoming even more obvious after contrast enhancement, which can be used to distinguish the portal vein in the porta hepatis [17]. The dilated common bile duct lies adjacent to the duodenum and head of the pancreas. Enlargement of the head of the pancreas, particularly if irregular or knobby, is usually due to pancreatic carcinoma but occasionally results from lymphoma or metastatic growth to lymph nodes from a colonic carcinoma. When the obstruction affects predominantly the right or the left hepatic duct the intrahepatic biliary dilation will correspondingly affect either the right or left lobes of the liver (Fig. 11).

Space-occupying Lesions

The main use of computed tomography in liver diagnosis is in detecting hepatic masses and distinguishing solid and fluid lesions. Such lesions can at present be demonstrated when only 1-2 cm in diameter, and tumours can usually be distinguished from cysts[18].

Simple Cysts

Liver cysts are not uncommon. They are usually single and small but may be large or multiple, and polycystic disease of the liver may be associated with polycystic
In some countries such as Iraq and Saudi Arabia where dogs and sheep are infested, hydatid disease is the commonest cause of masses within the liver.

**Trauma**

Disintegration of liver substance due to trauma without a superficial laceration results in a large irregular low density area. Haemorrhage around the liver, particularly within the first 24 hours, may be as dense as the liver and invisible unless there is contrast enhancement of the liver parenchyma. Subsequently, free peritoneal blood has similar appearances to ascites on computed tomography[20].

**Tumours**

Solid tumours of the liver produce similar appearances whether benign or malignant, metastatic growths or hepatoma. The liver is usually enlarged and expanded by tissue of lower density. The margins of most metastatic growths are ill-defined and then often irregular in shape (Fig. 13), but localised well-defined tumours also occur and are then much more easily recognised. A hepatoma is usually a single tumour producing one well-defined expanding area in the liver (Fig. 14). However, some tumours have the same density as liver parenchyma and show only after contrast enhancement[21]. From recent studies it would appear that about 2-5 per cent of tumours will be shown only after contrast enhancement; about 15 per cent are more easily seen after contrast enhancement and about 15 per cent are seen best on unenhanced scans[22].

Irregular areas of calcification occur in a minority of tumours but especially in hepatomas and metastases from colloid carcinoma[23]. Tumours may also undergo

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**Hydatid Cysts**

Echinococcal cysts of the liver may be indistinguishable from simple cysts but in approximately two-thirds of cases the appearances are specific. Peripheral septa attached to a slightly higher density central region are commonly seen as well as a thin peripheral capsule that is occasionally calcified, producing an obvious dense rim[19].

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**Fig. 11.** Dilated intrahepatic bile ducts more marked in the left lobe of the liver shown after contrast enhancement. (k—kidneys; St—stomach; Sp—spleen; A—aorta).

**Fig. 12.** Multiple cysts (C) in the liver (L). (A—aorta; St—stomach; Sp—spleen).

**Fig. 13.** Multiple metastatic growths in the liver shown without contrast enhancement.
central necrosis and liquefaction, especially when responding to chemotherapy. On computed tomography they show very low density central areas.

Abscesses

Intrahepatic abscesses are usually associated with intra-abdominal sepsis or following choledochoduodenostomy or sepsicaemia and produce areas of low tissue attenuation with values in the region of 6-14 EMI units. They are therefore easily visible. After contrast enhancement, abscesses are not only more clearly seen but often show transecting bands not visible on the unenhanced scans (see Fig. 10).

Abscesses are commonly found in the right lobe of the liver. They are often quite large but may be multiple and are usually rounded with surrounding liver substance clearly visible.

In association with liver abscesses there may be irregular areas of liver parenchyma of lower density, but not as low as that of abscesses (Fig. 15), which disappear on contrast enhancement. The cause and nature of this lesion is at present not known but probably indicates an area of 'hepatitis' or possibly infarction adjacent to the liver abscess.

Amoebic and pyogenic abscesses have identical appearances, and approximately one-third of hydatid cysts may also show just as a large uniform low density area with a very thin outer rim or capsule.

Abscess Drainage and Aspiration. The clear visibility and exact localisation of subphrenic and intrahepatic abscesses with computed tomography makes percutaneous aspiration and drainage a relatively simple and precise procedure (Fig. 16[24]).

The position and depth of the abscess is shown on a scan and then the direction of the needle used for the local anaesthetic acts as a guide for the aspiration needle or Argyle tube. Other than with small abscesses, localisation is rapid and the procedure saves a laparotomy. However, the pleura must be studiously avoided for fear of producing an empyema. The aspirate must, of course, always be sent for microbiological examination and also for biochemical analysis when indicated.

Fig. 15. (a) Low density area in the liver (arrows) which (b) largely disappears after contrast enhancement. Localised hepatitis? Lesion adjacent to healing liver abscess (arrowhead — gallbladder).
Extrahepatic Lesions

Large tumours and cysts in the right upper abdomen, especially those lying posteriorly, are intimately related to the right lobe of the liver, and it is then not possible to be sure of the origin of the 'mass' lesion (Fig. 17). A non-functioning kidney on a pyelogram would suggest a renal origin, and displacement of the kidney and ureter anteriorly a retroperitoneal origin. In some of these cases a radiological diagnosis can only be made by showing the blood supply of the tumour by arteriography. It then becomes possible to differentiate a cystic renal carcinoma, suprarenal carcinoma, retroperitoneal sarcoma and a ganglion neuroblastoma arising in the sympathetic chain.

Vascular Lesions

An aneurysm of the hepatic artery can also produce the appearance of a space-occupying lesion and on computed tomography may resemble a cyst, particularly when there is marginal calcification. Its true nature can be demonstrated by 'angiotomography', that is by taking scans through the lesion immediately after the intravenous contrast medium has been given.

It has recently been shown that occlusion of hepatic artery branches leads to cyst formation within the liver. It is possible therefore that hepatic artery thrombosis or embolism may manifest themselves as liver cysts.

Calcification of a thrombus within the inferior vena cava.
cava as it is enclosed by the liver is clearly visible and indicates inferior vena caval obstruction (Fig. 18a, b).

Gallbladder
Computed tomography is rarely used in the diagnosis of gallbladder disease or cholelithiasis because of the expense and because oral cholecystography and ultrasonography provide the necessary information in the vast majority of cases. However, computed tomography is a very effective way of clearly demonstrating the size, shape and position of the gallbladder and cholelithiasis (Fig. 19). The normal gallbladder wall can also be shown but requires contrast enhancement.

Compared tomography has been used in acute cholecystitis with empyema to show an enlarged gallbladder, thickening of the gallbladder wall (Fig. 20), and even surrounding inflammatory changes in the adjacent mesentery[25]. A carcinoma of the gallbladder can be diagnosed when there is no normal gallbladder but a soft tissue mass is visible in its place (Fig. 21).

Thus, in gallbladder and biliary disease computed tomography is particularly valuable in showing intrahepatic dilatation of bile ducts when for technical reasons it is not demonstrable on ultrasonography, and in showing the dilated gallbladder with a thickened wall in acute cholecystitis.

Fig. 18. Calcification in the inferior vena cava (arrows) indicating a complete obstruction. (a) Calcification of inferior vena cava (arrow) indicating thrombosis and obstruction. (b) Associated enlargement of azygos vein (arrow).

Fig. 19. Gallstone in gallbladder (arrow). (L—liver; I—inferior vena cava; A—aorta; Ps—psoas; K—kidneys—lower poles; C—colon).

Fig. 20. Enlarged gallbladder with thickened wall in a case of empyema of the gallbladder. Note also enlarged spleen (Sp). (L—liver; GB—gallbladder; K—kidneys).
one of high cost, but where available it can be used to supplement ultrasonography in difficult and equivocal cases and where interfering bowel gas precludes such an examination. Haemochromatosis and fatty infiltration of the liver are shown and can be quantified by computed tomography but not with the other scanning methods.

One of the most important advances in the management of focal liver disease has, however, now been inaugurated[26]. The detection of space-occupying lesions allows accurate needle placement for cytological and microbiological examination. Furthermore, percutaneous drainage of subphrenic and intrahepatic abscesses can be carried out, saving an otherwise inevitable laparotomy.

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Conclusions
While this article is concerned mainly with computed tomography in the diagnosis of liver and gallbladder disease, other modalities, particularly isotope scanning and ultrasonography, can give similar information. Isotope scanning shows areas of non-uptake of the radio-pharmaceuticals of lesions greater than 3 cm in diameter, but cysts, abscesses and tumours have a similar appearance. Patchy areas of non-uptake of the isotope also occur in parenchymal disease such as cirrhosis and fatty liver. The largely non-specific appearances of isotope scans and the poor anatomical display is a severely limiting factor, although it is extremely effective as a screening procedure in separating cases with normal and abnormal livers.

Ultrasonography is vastly more specific and gives much better anatomical information. The portal veins can be distinguished from hepatic veins, dilated intrahepatic bile ducts can be visualised, and cystic and solid lesions produce quite different appearances. Adjacent organs are shown on each section, which can be performed in axial, transverse and oblique planes. Lesions of 1-2 cm are often readily visible. Thus, in the vast majority of cases mass lesions can be shown by ultrasonography.

This technique is, however, more than any other scanning procedure, dependent on the skill and knowledge of the individual performing the examination and the information, even with the latest grey scale equipment, is not as immediately obvious as with computed tomography.

In about 10 per cent of cases intervening bowel gas precludes an effective examination and bone and the lung bases cannot be visualised. In spite of these limitations ultrasonography is ideally suited to liver and gallbladder diagnosis and because it is considerably cheaper and quicker than computed tomography will inevitably be preferable. Ultrasonography is certainly the method of choice in gallbladder disease and in demonstrating intrahepatic bile duct dilatation.

The disadvantage of computed tomography is entirely