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Planning of Liver Surgery Using Three Dimensional Imaging Techniques

M.S. van Leeuwen, J. Noordzij, A. Hennipman and M.A.M. Feldberg

In the simplified Couinaud classification, in which the liver is divided into eight segments, each supplied by a central vasculo-biliary sheath, little attention is given to the high prevalence of anatomical variations which occur, especially in the right hemiliver. Using volumetric acquisition techniques, such as magnetic resonance imaging or spiral computed tomography scanning, detailed insight into the individual segmental anatomy can now be obtained in a non-invasive manner. The significance of this anatomical insight lies in the planning of anatomical resections, whereby the relationship between tumour and individual segmental anatomy can be depicted in a three-dimensional format. As such, three dimensional (3D) liver imaging helps to design an individualised resection, tailored to the topographical relationship between individual segmental anatomy and tumour tissue present. Three dimensional liver imaging is of most practical value if a resection of one or more segments or sectors is considered, especially in the right hemiliver. In these cases, 3D liver imaging can demonstrate the precise location of the scissuras to the surgeon pre-operatively.

Key words: computed tomography, three dimensional, liver, anatomy, liver surgery
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INTRODUCTION

Although there is international agreement on many aspects of liver anatomy, nomenclature varies from country to country. In this review, the French nomenclature, introduced by Couinaud and adapted by Bismuth, is used [1, 2].

PRINCIPLES OF LIVER SURGERY

Techniques in liver resection

For a successful curative liver resection, two opposing demands must be satisfied. The tumour should be removed with sufficient tumour-free margin, whilst enough normal parenchyma has to be preserved in order to prevent postoperative liver failure. These goals can be met by performing anatomical or extra-anatomical resections [1–5].

Extra-anatomical resections

In extra-anatomical resections, the location of the resection planes is defined by the presumed extent of the pathology. Consequently, the individual portal or suprahepatic segmentation pattern does not influence the extent of the planned resection. Extra-anatomical resections are frequently used for relatively small, peripheral tumours.

Anatomical resectionns

In anatomical resections, resection planes are defined by the portal segmentation (Figure 1). Pathology is located with respect to the portal segmentation, and the entire portal sector, segment, or combination of segments which contain tumour are resected.

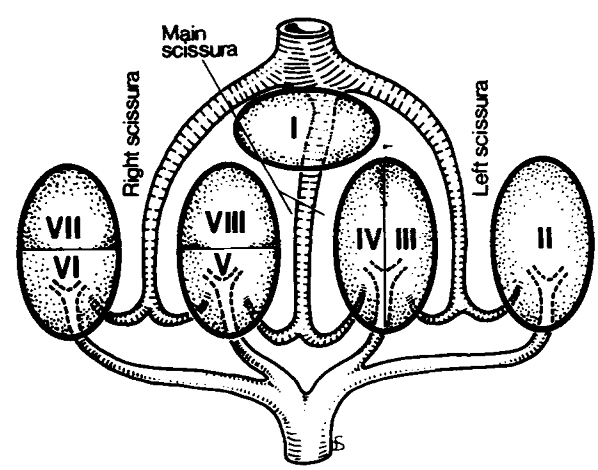

Figure 1. Schematic representation of the internal anatomy of the liver (reproduced from Bismuth [16]). Portal segmentation of the liver into areas supplied by the structures in one vasculobiliary sheath. Reprinted from Blumgart LH, *Surgery of the Liver and Biliary Tract* © 1988, with kind permission from Churchill Livingstone, Edinburgh.

Because resection is performed along the avascular planes, or scissuras, between adjacent portal territories, blood supply and bile drainage of the remaining liver segments is left undisturbed, and resection can be performed with little blood loss. Consequently, anatomical resection is the preferred technique if the size, number or location of tumours require resection of more than a peripheral wedge of liver tissue.

Several techniques are used to perform anatomical resections, and all require knowledge of the location of the appropriate

Correspondence to M.S. van Leeuwen.
All authors are at the Department of Radiology and Surgery, University Hospital Utrecht, Heidelberglaan 100, 3584 CX, Utrecht, The Netherlands.

scissuras along which the resection will be performed. Some scissuras have a corresponding landmark on the liver surface. The right sagittal fissure indicates the location of the main scissura between right and left hemiliver, and the left sagittal fissure identifies the relative avascular plane between left medial and left lateral segments. Anatomical resections performed along these planes will result in a right or left hemihepatectomy, or an extended right hepatectomy or left lobectomy, respectively.

Another approach to identify the hemiliver sector or segment which needs to be resected is to isolate and clamp the afferent vessels to the appropriate liver segments. The lack of perfusion in the area supplied by the clamped vessels results in a sharp demarcation of the corresponding segments. Consequently, this approach requires identification of the appropriate vascular and biliary structures. In the extrahepatic approach, the peritoneum of the hepatoduodenal ligament is opened, and the structures in the hepatic pedicle are dissected free. This approach is often used for hemihepatectomies. Once the structures supplying the appropriate hemiliver are identified and ligated, the parenchyma can be divided along the resulting line of discolouration. One disadvantage is that the anatomy within the region of dissection varies between individuals: the portal vein, hepatic artery and bile duct all have their individual location, course, and branching pattern. In addition, anatomical variations of each of the three elements are very common. Consequently, great care must be taken to prevent inadvertent ligation of the wrong bile ducts or arterial and portal vessels, which makes the procedure time-consuming. Another limitation of the technique is that it does not allow identification of right sectorial or segmental branches, since these originate in the right extremity of the hilum, which is often inaccessible, buried deep in the liver substance. In contrast, the left segmental branches arise in the umbilical fissure, and therefore, the origin of these branches can be approached extrahepatically.

An alternative to the extrahepatic approach is the glissonian approach [6]. In the glissonian approach, an incision is made in the liver parenchyma close to the expected location of the vasculo-biliary sheath which supplies the sector or segment which needs to be resected. Once the sheath is identified, the entire sheath (and the structures it contains) is clamped. The resulting discolouration of the corresponding liver area demonstrates the segmental location corresponding to the clamped sheath. Subsequently, the parenchyma can be safely dissected along the precise delineation of the sector or segment. The major advantage of this technique is that it allows the identification of the avascular planes between segments, which makes it well suited for resection of sectors or segments. Also, because only the structures to the appropriate part of the liver are interrupted, anatomical variants in the hilar region are not encountered. Although this technique has gained wide acceptance in France and, to a lesser degree, in other countries in Europe, it has remained relatively unkown in English-speaking countries.

Liver anatomy relevant to anatomical resections

The identification of scissuras is an essential prerequisite for anatomical resections. At laparotomy, the right and left sagittal fissure, corresponding to the resection plane of a hemihepatectomy, or an extended right hepatectomy or left lobectomy, respectively, are easily identified. However, identification of other scissuras is not possible on the surface of the liver. Therefore, intra-operative ultrasound is often used to identify vascular structures and mark them on the liver surface. Thus, the right hepatic vein is often used as a landmark to indicate the position of the right scissura, and the right portal trunk is used as a landmark to indicate the transverse scissura in the right hemiliver.

If a glissonian approach is used, ultrasound can be used to identify the location of first and second order vasculobiliary sheaths. However, because ultrasound can image only one plane at a time, it is not well suited to appreciate the individual portal segmentation.

THREE-DIMENSIONAL DISPLAY OF LIVER ANATOMY

In order to assess liver anatomy *in vivo*, cross-sectional imaging techniques can be adapted to create volume acquisitions. Magnetic response imaging (MRI) is able to generate truly contiguous slices, and the intrinsic contrast between vessels and parenchyma makes it a suitable modality for three-dimensional (3D) liver imaging [7, 8]. Spiral computed tomography (CT) is even better for volume acquisitions of the liver. The volumetric data are acquired in one breath hold, and overlapping reconstructions can be generated to improve spatial resolution along the longitudinal axis [9–13].

Requirements of 3D display of surgical anatomy of the liver

A 3D display of liver anatomy should present all relevant anatomical information in a coherent, comprehensible manner. To achieve this goal, five steps have to be undertaken [14].

The first step is to consider what anatomical information is relevant to the resection being planned. The tumour(s), the hepatic veins and the portal veins, including segmental branches, are the internal structures to be displayed. The gall bladder fossa, umbilical fissure, transverse fissure, and fissure for the ligamentum venosum are the external structures to be displayed, since they serve as landmarks for the surgeon during the operation.

The second step is the selection of the cross-sectional images most appropriate for reconstruction into a 3D data set. CT and MRI are both capable of acquiring a set of contiguous transverse sections, displaying all relevant anatomical structures. It will depend on the institution and the specific imaging equipment available, whether CT, CT during arterial portography (CTAP) or MRI data will be used for the 3D reconstruction [7, 8, 13, 15].

The third step is the actual 3D reconstruction. This is a computational process which requires interaction by a person with anatomical expertise. In general, this process takes place at an image analysis workstation. The process starts with segmentation; on subsequent transverse sections, the relevant anatomical structures are identified and demarcated. Each anatomical entity needs to be defined separately. Thus, the liver parenchyma, hepatic veins, portal vein branches and tumour(s) are demarcated on each cross-sectional image. Subsequently, the successive 2D-contours of each anatomical entity are combined into a single data set, which represents the outline of that structure in a 3D-coordinate system. Thus, 3D data sets of the liver parenchyma (including indentations and fissures), portal vein system, hepatic veins and tumour(s) are created. Because these 3D data sets, each representing one anatomical entity, are generated from the same series of cross-sectional images, the 3D spatial relationships between the different structures can be accurately reconstructed.

The fourth step is the visualisation of the reconstructed 3D data sets. By means of another computational process called rendering, realistic 2D projections of the 3D data sets can be generated and displayed on a monitor. The operator of the system can choose which selection of 3D data sets is to be displayed. Similarly, the direction of the 3D projection can be chosen; upper, lower, anterior, side views, or any other desired projection can be calculated and displayed (Figure 2).

The fifth and final step is the production of a series of images which best convey the anatomical relationships pertinent to the patient studied, and the operation under consideration. These images may be stored on the magnetic disk in the system, and a selection of images may be printed as hard copies. Alternatively, a video can be recorded which allows for dynamic rotations to better convey the relationship between different anatomical structures.

It is important to address the question whether detailed preoperative knowledge of the portal segmentation and the hepatic venous anatomy by means of 3D liver imaging is always useful, since during the operation external landmarks on the liver surface guide the surgeon to specific anatomical planes. Futhermore, by means of intra-operative ultrasound, lesions to be resected and intrahepatic vascular structures can be accurately localised.

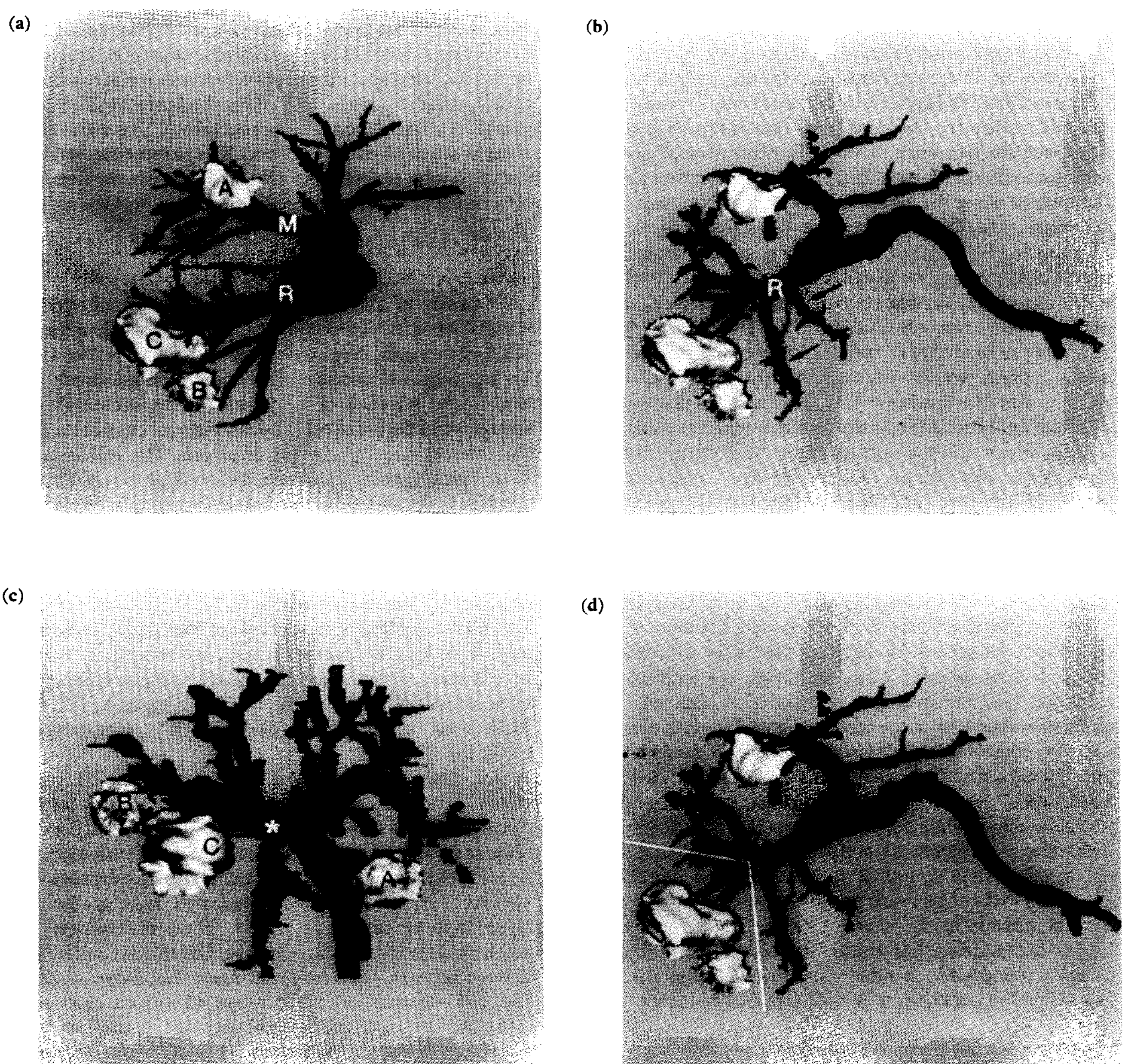

Figure 2. A patient with colorectal liver metastases. (a) Caudocranial view of the lesions and the hepatic veins demonstrate one lesion (A) overriding the middle hepatic vein (M), and two lesions in the right hemiliver, one (B) in the posterior sector and one (C) overriding the plane of the right hepatic vein (R). The location of the lesions suggests an extended right hepatectomy as an appropriate resection. (b) Caudocranial view of the lesions and the portal system demonstrates the existence of right posterior portal segmental branches (arrows), arising directly from the right portal trunk (R). (c) Right lateral view of the lesions and portal system shows that the lesion in the medial segment (A) is located below the level of the transverse scissura, as indicated by the right portal trunk (asterisk). The lesions in the right hemiliver (B, C) are located at the level of the transverse scissura. (d) Based on these findings, a combined resection of the inferior part of the left medial segment (segment 4b) with a rim of the adjoining part of the right anterior sector and a deep wedge resection (lines) of the lateral aspect of the right hemiliver was performed, leaving the major part of the right hemiliver in place (reproduced from van Leeuwen *et al.* [14]). Reprinted from Tytgat GNJ, Reeders JWAY, eds. *Diagnostic Imaging of the GI Tract*, pp. 121–133 © 1995, with kind permission from Bailliere Tindall.

The gall bladder fossa is a reliable indicator of the scissura between right and left hemiliver, and teres ligament indicates the plane between medial and lateral segments in the lower part of the left hemiliver. However, the external liver anatomy does not allow further subdivision of the liver.

The limitation of intra-operative ultrasonography is that it is very difficult to acquire an overview of the different intrahepatic vascular systems. Consequently, the individual portal segmentation cannot be assessed, and the hepatic veins are used as landmarks instead. This approach works well if the main scissura between right and left hemiliver has to be localised, since it is always located in the plane of the middle hepatic vein. However, in the left, and especially in the right hemiliver, no unambiguous topographic relation between the hepatic veins and the scissuras exists [1, 3, 7, 13]. Therefore, 3D liver imaging is of practical value if a resection of one or more segments or sectors is considered, especially in the right hemiliver. In those cases, 3D liver imaging can demonstrate the precise location of the scissuras to the surgeon pre-operatively [8, 14, 15].

During such a resection, intra-operative ultrasound can be used to correlate the anatomical information of the pre-operative 3D liver images with the real-time sonographic findings in order to indicate the precise location of the appropriate resection planes.

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