Sonographic preoperative assessment of liver volume before major liver resection

Évaluation préopératoire des volumes hépatiques par échographie avant résection du foie

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Summary
Objective. — The use of ultrasonography is widespread for both the diagnosis and treatment of liver tumors. However, the measurement of liver volume by ultrasonography is not commonly done. We report an original method of liver volumetry using ultrasonography and an investigation into the usefulness of ultrasonography in this context.

Methods. — The data for 50 patients undergoing various types of major hepatectomy were collected. We preoperatively measured liver volume using ultrasonography, dividing the liver into three main compartments according to precise anatomical landmarks, and then made comparisons with the volume of the actual specimen after hepatectomy, for all of the study participants.

Results. — Total volume correlation between the two groups was good ($r = 0.916$, $P < 0.001$). However, the correlation was weaker in cases of right hepatectomy compared with other types of hepatectomy.

Conclusion. — This study demonstrates the possibility of doing liver volumetry using an ultrasound device. Further investigation to establish the reliability of this easily available and noninvasive approach is needed.

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Résumé
Objectifs. — L'échographie transcutanée est fréquemment utilisée pour le diagnostic et le traitement des tumeurs du foie. Cependant, la mesure du volume du foie par échographie n'est pas utilisée en pratique. Nous rapportons une méthode originale de volumétrie hépatique par échographie.

Méthodes. — Les données de 50 malades devant avoir divers types d'hépatectomie majeure ont été recueillies. Le volume préopératoire du foie a été mesuré par échographie, divisant le foie...
en trois compartiments à l’aide de repères anatomiques précis. Les mesures échographiques ont été comparées au volume des pièces opératoires.

Résultats. — La corrélation entre la volumétrie échographique et de la pièce opératoire était globalement bonne ($r = 0.916, p < 0.001$). La corrélation était cependant plus faible en cas d’hépatectomie droite qu’en cas de résection d’un autre type.

Conclusions. — La volumétrie hépatique par échographie est faisable. Une validation de cette méthode non invasive aisément disponible est cependant indispensable.

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Introduction

Recent advances in the instrumentation and refinement of surgical techniques have made it possible to carry out various types of hepatectomy, while the mortality and morbidity associated with such procedures have gradually decreased. However, the incidence of lethal complications remains at around 4% [1—3].

Following liver resection, the risk of postoperative acute liver failure depends on liver volume as well as on the quality and function of the remaining parenchyma, including its regenerative capacity. In non-cirrhotic livers, postoperative liver failure is observed after major hepatectomy — resection of three or more liver segments — according to Couinaud [4], particularly in fat-infiltrated livers, or when planning a right lobectomy when the left lateral segment is reduced. Under such circumstances, preoperative knowledge of the volume of each liver segment should allow prediction of the remnant volume after any type of hepatectomy and, to a degree, the risk of postoperative liver failure. Furthermore, while planning extended major resection, assessment of the remnant volume may facilitate a decision on preoperative portal vein embolization (PVE), the effects (such as regeneration) of which can be followed-up by the same method of volume measurement.

We report here on the accuracy of an ultrasonographic method of liver volume assessment based on partitioning the liver into three compartments, excluding segment I. These preliminary results were obtained prospectively from a population of 50 patients undergoing major liver resection and compared to the actual volumes of the resected specimens.

Methods

From September 1999 to August 2003, 351 hepatectomies involving 321 patients were performed at the Department of Digestive and Hepatobiliary Surgery at Pitié-Salpêtrière Hospital in Paris. A total of 184 major anatomical hepatectomies (right hepatectomy, extended right hepatectomy, left hepatectomy and left lateral segmentectomy) were performed (52.4%). Of these 184 patients, 115 had hepatic pathologies, including cirrhosis, and 69 had normal livers. Measurements of liver volume using ultrasonography failed in 19 patients because of variations in their anatomy. Consequently, 50 patients were finally enrolled in this study (Fig. 1). There were 28 men and 22 women, with a mean age at diagnosis of 62 (range 21—84) years. Most patients had a tumor (malignant, $n = 44$; benign, $n = 4$), while one patient had intrahepatic biliary lithiasis, and another had a traumatic liver injury (Table 1).

Ultrasonography was performed in all patients, by an experienced sonographer, using one scanner (Hitachi Katana EUB 525, Japan) equipped with a 3.5-MHz convex probe. All sonograms were obtained via a subcostal or intercostal window, with the patient in the supine position. Patients were fasted for 6h before imaging. In patients with a small liver situated high in the right subphrenic space, the ultrasonography view of the liver is limited, as it can only be obtained through an intercostal window. Thus, fixing two landmarks and calculating the distance between them may be impossible in such cases.

<table>
<thead>
<tr>
<th>Causes of hepatectomy</th>
<th>Patients (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metastatic tumor</td>
<td>32</td>
</tr>
<tr>
<td>Hepatocellular carcinoma</td>
<td>12</td>
</tr>
<tr>
<td>Adenoma</td>
<td>4</td>
</tr>
<tr>
<td>Intrahepatic biliary lithiasis</td>
<td>1</td>
</tr>
<tr>
<td>Traumatic liver injury</td>
<td>1</td>
</tr>
</tbody>
</table>
Volumetry method using ultrasonography

The liver was divided into three compartments: segments II—III (left lateral segment); segment IV; and segments V—VIII (right lobe). These compartments (Fig. 2) were selected as they can be configured into simple geometrical shapes that can be easily superimposed on the general shape of the corresponding parts of the liver. The volume (in cm$^3$) of each compartment was calculated from three measures (in cm): $H$: height; $T$: thickness; and $W$: width.

Each distance was carefully measured, several times where necessary, using manual landmark calipers after completion of the real-time examination. Liver volume was automatically calculated using the function contained in the ultrasonography device.

The measurements were calculated in the following manner:

- the right lobe, segments V + VI + VII + VIII, was configured as an ellipsoid by the formula $H \cdot T \cdot W / H^2 + T^2 / 6$ in which:
  - the height ($H$) was measured on a sonographic longitudinal scan, from the lower part of the liver to the upper part of the dome of the diaphragm,
  - the thickness ($T$) was measured on the same longitudinal scan under the ribs — perpendicular to the $H$-axis, where the liver is estimated to be thickest — from the anterior aspect of the liver to a point usually situated just above the right kidney,
  - the width ($W$), using a sub- or intercostal transverse scan, was the maximum gap between the origin of the right branch of the portal vein and the right edge of the liver;
- segment IV was configured as a section of a cylinder by the formula $H \cdot T \cdot W / 4$ in which:
  - the height ($H$) was measured from the middle of the lower edge of segment IV to the end of the middle or left suprahepatic vein,
  - the thickness ($T$) was measured on the same longitudinal scan under the ribs — perpendicular to the $H$-axis, where segment IV was considered to be thickest, an area usually found just above the porta hepatis — from the anterior edge of segment IV to its posterior limit at the portal division and/or anterior edge of the caudate lobe,
  - the width ($W$) was determined on a subcostal transverse scan aligning the portal division with the umbilical portion of the left portal vein and the Rex recessus. $W$ was thus the maximum distance between the Rex recessus and the intrahepatic section of the middle suprahepatic vein at the level of the right portal vein;
- the volume of the left lateral segment was configured as a quarter of an ellipsoid by the formula $H \cdot T \cdot W / H^2 + T^2 / 6$ in which:
  - the height ($H$) was measured from the lower edge of segment III close to the round ligament to the end of the left suprahepatic vein,

![Figure 2](image_url)

**Figure 2** Paired ultrasonography images and corresponding schematic representations showing ultrasonography measurements of the three dimensions. Left column: sonograms; right column: schematic views; A: right lobe; B: segment IV; C: left lobe.
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... corresponded to the volume of the specimen.

... was calculated by the water-displacement method. The actual parenchymal transection line was decided according to Couinaud’s liver segments.

... the width (W) was determined on a transverse scan under the xiphoid, aiming for the end of the left lobe on the left, and the umbilical portion of the left portal vein and the Rex recessus on the right. W was thus the maximum gap established between the umbilical portion of the left portal vein and the end of the left lobe.

Surgical procedure

A right subcostal incision was extended to the left and an upper median incision was made in all patients. All hepatectomies were carried out according to Couinaud’s liver segments. Left lateral segmentectomy consisted of the resection of segments II and III. Left hepatectomy consisted of complete resection of segments II, III and IV. Right hepatectomy consisted of resection of segments V, VI, VII and VIII. Extended right hepatectomy consisted of complete resection of segments V, VI, VII and VIII, and partial or complete resection of segment IV, without resection of the caudate lobe (segment I). Vascular occlusion was carried out either by inflow control (Pringle maneuver) or by inflow and outflow control (total vascular exclusion). The liver parenchyma was transected by a crush-clamp technique. The actual parenchymal transection line was decided upon by intraoperative ultrasonography in all patients.

The resected liver volume was determined by the water-displacement method, using a sterilized glass container. This graduated, cylindrical container was filled with sterile physiological saline to a precise level (a); after careful immersion of the liver specimen in saline, the level in the graduated container was recorded (b). The subtracted volume (b−a) — namely, the displaced water — corresponded to the volume of the specimen.

Data collection

Data were prospectively recorded and analyzed according to the following factors: the type of hepatectomy; the volume of the specimen calculated by the water-displacement method; and the volume determined preoperatively by ultrasonography.

As the volume of each compartment assessed by ultrasonography included blood volume and as there was no blood in the large vessels of the resected specimens, we assumed that the ultrasonography-visible vascular bed represented 15% of the whole liver volume and, thus, added a 15% increment to the specimen volume before comparison. The percentage difference between the ultrasonography volume and specimen volume (plus the 15% increment) was calculated according to the equation:

\[
\frac{\text{ultrasonography volume} - \text{specimen volume} \times 1.15}{\text{specimen volume} \times 100}
\]

Statistical methods

Data were expressed as means ± standard deviation (SD). The relationship between the two liver-volume values obtained by the two different methods (sonographic volumetry and specimen volume calculated by the water-displacement method) was investigated using single regression analysis. Four groups were defined according to liver resection type: left lateral segmentectomy; left hepatectomy; right hepatectomy; and extended right hepatectomy. The percentage differences among the four groups were tested by analysis of variance (ANOVA). Less than 5% was considered a statistically significant difference.

Results

Details of hepatectomy

The following types of hepatectomy were carried out: left hepatectomy (n = 6; 12%); left lateral segmentectomy (n = 13; 26%); right hepatectomy (n = 21; 42%); and extended right hepatectomy (n = 10; 20%). Of the 10 patients undergoing extended right hepatectomy, three had complete resection of segment IV, six had half of segment IV resected, and one had 80% of segment IV resected.

Liver volume by ultrasonography

The volumes of the left lateral segment (segments II and III), left lobe, right lobe and right lobe plus segment IV were 343.6 ± 35 mL (range 170–563), 366.1 ± 70.1 mL (range 176–689), 851.9 ± 50.6 mL (range 429–1203) and 1014 ± 122.5 mL (range 568–1650), respectively.

Actual volumes of specimens

Specimen volumes were 302.7 ± 51 mL (range 130–500), 318.9 ± 34.5 mL (range 140–475), 696.2 ± 41.6 mL (range 450–1140) and 838 ± 111.7 mL (range 500–1350) for the left lateral segment, left lobe, right lobe and extended right lobe, respectively. After correction — adding 15% — these values became 348 ± 58.7 mL (range 150–575), 366.8 ± 39.7 mL (range 161–546), 800.1 ± 47.2 mL (range 518–1311) and 964 ± 116.8 mL (range 575–1553), respectively.

Correlation between ultrasonography volumes and corrected specimen volumes

There was a significant correlation between the specimen volumes with the added 15% increment and the values from sonographic volumetry. The slope of the regression line was approximately 1.0 (0.956) and the correlation coefficient was \( r = 0.916 \) (\( P < 0.001 \)) (Fig. 3). There was no significant difference in percentages among the four groups (Fig. 4).
Figure 4 Percentage differences and means ± SD of ultrasonography volumetry compared with the volume of each specimen in the four groups according to type of hepatectomy. ANOVA: analysis of variance; RH: right hepatectomy; e-RH: extended right hepatectomy; LH: left hepatectomy; LLS: left lateral segmentectomy.

Discussion

Advances in surgical techniques and instruments, and a greater knowledge of the liver and its diseases, have contributed to an expansion of the indications for liver resection. Indeed, the liver surgery armamentarium has grown considerably over the past few decades, resulting in improved postoperative results and increased cure rates. Besides new techniques such as thermal ablation or cryotherapy and preoperative portal vein embolization, various types of extended and limited hepatectomy using different techniques are now available, and may be tailored to each individual case. However, the incidence of postoperative hepatic failure remains one of the most challenging problems [5—11].

Among the factors that can lead to hepatic failure, excessive hepatectomy and its consequentially extremely small volume of the remnant liver are among the major factors determining irreversible hepatic dysfunction. However, what the minimal amount of liver required is to avoid definitive dysfunction remains to be ascertained. Despite this lack of data, a precise preoperative assessment of morphological volume is still essential as it may help to more accurately select patients suitable for major liver resection and, thus, lower the incidence of acute hepatic failure.

This was a report of a method of preoperative liver volume assessment using ultrasonography. Its accuracy was studied by comparing ultrasonography results with the volumes of the resected specimens.

At present, computed tomography has become widely accepted and is now performed to acquire a detailed pre-operative volume of the liver. Although this method of volumetry is technically well established, computed tomography has a few drawbacks: it gives much higher exposures to radiation than other X-ray diagnostic devices; there is a risk of developing nephropathy due to the contrast medium; and it is time-consuming. Despite these issues, it is frequently used because of its high objectivity and high reproducibility [12—19].

On the other hand, the use of ultrasonography is also widespread, and it offers clear benefits such as non-invasiveness, low-cost and easy repetition. Furthermore, various other functions are now being developed and incorporated into the ultrasonography devices. Once simply a diagnostic tool, it has become today an adjunctive treatment in some indications.

Surprisingly, given the widespread use of ultrasonography, its use for liver volume assessment has seldom been studied. In 1952, Howry and Bliss presented the first ultrasonic cross-sectional pictures and scans of the liver [20]. Stigsby and Rasmussen [21] and Rasmussen [22] described their technique of liver volume measurement in 1971 and 1972, respectively. However, ultrasonography did not achieve popularity due to the complexity of its manipulation but, most of all, the modern built-in functions of the current ultrasonography devices were not yet available in those days.

In fact, ultrasonography measurement of liver volume is difficult. First, the shape of the liver is subject to wide individual variation. Second, it is difficult to establish the optimal method of measurement due to the morphological peculiarities of the liver in a given patient. Third, the scanning fields may be obstructed by gas in the bowels and lungs, and can be limited in obese patients and in those who have respiratory dysfunction. Indeed, in most cases, the convex superior surface of the liver is overlapped by the lung, thereby obstructing the ultrasonography beam. Finally, reliability depends greatly on the ultrasonography operator’s skill.

In spite of these difficulties and because of its obvious advantages, several studies of liver volumetry using ultrasonography have been published [23—25]. However, in all of these reports, liver volume was calculated from longitudinal slices of a certain thickness and defined as the sum of the individual volumes of each slice. Despite being simple, this method is extremely time-consuming.

For this reason and following a worldwide demand, major progress in the design and functionality of ultrasonography devices was made. Today, nearly all devices include automatic volume calculation using three dimensions. Thus, in our present series, we attempted to measure liver volume with this function, ascribing to each segment a specific geometrical shape.

Two issues have been of major importance in undertaking an investigation of ultrasonography measurement of liver volume before major hepatectomy. First, it has always been easier and quicker to conduct ultrasonography examinations of patients because it is done within the department of surgery, unlike computed tomography scans, which must be requested from the department of radiology. Second, in the early days of the present study, a computed tomography device for liver volumetry was not well developed, so satisfactory results were not reliably obtained.
To determine liver volume, we manually fixed every point to measure three dimensions for each segment: height, thickness and width. After manual measurement of these three dimensions, the corresponding volume was calculated automatically by software, according to the particular shape of the segment involved. Thus, the result is strongly dependent on the manual setup of the three dimensional axes.

Liver volume measured by ultrasonography always includes vascular volume and, specifically, the major intrahepatic volume. On the other hand, this blood is lost from those vessels in the resected liver. This explains the frequent discrepancy between the volume of the specimen and the volume measured by ultrasonography. For this reason, ultrasonography measurement of the parenchymal volume and blood volume should ideally be done separately. However, specific assessment of the volume of the visible liver blood bed is difficult with ultrasonography. In addition, the blood volume of a diseased liver with, for example, liver cirrhosis is probably different from that of a healthy liver.

The number of patients with chronic liver damage is increasing annually across all racial, ethnic and age groups. In particular, the dramatic increase in patients with liver pathology associated with hepatitis C viral infection throughout the world is of global health significance. Thus, many factors must be considered when making comparisons. In fact, more than 60% of the patients undergoing a major anatomical hepatectomy in our institution had a liver pathology. The purpose of the present study was to assess an original method of measuring liver volume using an ultrasound device, and to evaluate the accuracy of the method against preliminary data. This required the study of volumes under the same conditions, so 50 patients with no liver pathology were finally selected.

Normally, 100 g of liver contains 25—30 mL of blood [26]. Hwang et al. reported that blood volume of the right lobe was 29 ± 8 mL/100 g of liver in 12 survivors of liver transplantation [27]. However, the respective distribution of blood volume between the intrahepatic large and small vessels is not clear, nor is the amount of blood in the intrahepatic vascular bed, visualized by echography. Although this also applies to computed tomography as well as ultrasonography, the use of computed tomography to explore vessels was developed out of necessity, driven by the increase in major liver surgery. Nevertheless and despite this progress, several disadvantages of computed tomography, as described above, prevent its becoming a routine examination. In this case, the establishment of liver volumetry using ultrasonography is still to be regarded as an important medical issue.

In our study, we considered the visible vascular compartment volume to be 15% of the total liver volume and, therefore, added 15% of the actual volume of the specimen for comparison with the volume that was preoperatively measured using ultrasonography. Furthermore, patients with diseased livers, as confirmed by histopathology, were excluded as their liver blood compartment is reduced.

In our series of patients undergoing various types of hepatectomy, the ultrasonography method of liver-volume assessment proved to be clearly reliable. Furthermore, the percentage differences in ultrasonography volume compared with the specimen volume, obtained by considering each type of hepatectomy separately, showed no significant differences by ANOVA. Although the differences were not statistically significant, a slightly high standard deviation was seen in the right and left hepatectomy groups. We considered the parenchymal transection line in a right hepatectomy to be dependent on the frequent variations in the respective positions of the middle hepatic vein and the bifurcation of the portal vein. Sales et al. mention that the transection line in a right hepatectomy (the course of the middle hepatic vein) can be identified by three landmarks: the fundus of the cystic fossa; the porta hepatitis; and the termination of the left hepatic vein [28]. However, the relationship between the porta hepatitis and the portal bifurcation is highly variable. According to Couinaud, on the transectional view, the middle hepatic vein lies just in front of the portal bifurcation in only 40% of cases. In the remainder, the middle hepatic vein is situated in front of the right portal branch in a further 40% of the cases, and in front of the left portal branch in the remaining 20% [4]. Thus, in his view, the limits of the right lobe (the line of the middle hepatic vein) are identified by two landmarks: the fundus of the cystic fossa; and the left anterior point of the vena cava. Couinaud makes no mention of the second landmark described by Sales et al.

In our study, the left side of the right lobe was fixed at the origin of the right portal branch on ultrasonography — in other words, at the portal bifurcation. For this reason, there may be a discrepancy between the borders of the right lobe fixed by either ultrasonography or intraoperatively, as the middle hepatic vein is easier to recognize while planning the transection. This discrepancy depends ultimately on the position of the bifurcation of the portal vein in the porta hepatitis. Consequently, even a small difference between the line of measurement on ultrasonography and the actual transection line intraoperatively can lead to a vast difference between volumes.

Moreover, during surgery, the actual transection line frequently depends on the local anatomy of the small vessels and, in cases of malignancy, the transection line may be modified according to the rules of oncological surgery.

In the near future, it is expected that ultrasonography devices will be able to independently measure the volume of visible vessels, especially with the use of contrast medium and three-dimensional (3D) sonography with a freely movable transducer.

As for estimation of the volume of visible vessels, the addition of 15% to the specimens in this study provided good correlations, although further investigations are needed to determine the best means of measuring the volume of visible vessels with ultrasonography more precisely and in compliance with the anatomical variations of each type of parenchyma.

At this time, because liver volume by ultrasonography is calculated using different anatomical landmarks within the parenchyma, it is closely linked to the vascular anatomy of the liver. Indeed, under- or, more likely, overestimation of the remnant liver may result from any variation of any one of the reference points used for volume assessment. Thus, with this in mind, we suggest changing the method of measuring the width of the right hepatic lobe in the following way: the width (W) found on a subcostal or intercostal transverse sonographic scan is the maximum gap between the section of the main branch of the middle hepatic vein just in front
Figure 5  a. Liver volume is calculated by ultrasonography using different anatomical markers within the parenchyma; b. A new concept for measuring the right lobe. The width is measured as the maximum gap between the section of the main branch of the middle hepatic vein just in front of the portal vein, and the right edge of the liver.

of the origin of the right branch of the portal vein, and the right edge of the liver (Fig. 5).

This study did not include diseased livers. In such livers, the preoperative volume measurement is important, but not essential, as it represents only one among many other important factors in the decision-making phase before hepatectomy. Also, as most resections performed on such livers are minor and non-anatomical, evaluation of any method of volume measurement based on major vascular landmarks, such as ours, will be difficult. Finally, as described above, the intrahepatic blood compartment in diseased livers is reduced compared with that of healthy livers, probably as an effect of the stage of liver disease.

The clinical consequences of such liver variations warrant further investigations into the reliability of ultrasonography liver volumetry. Because computed tomography liver volume assessment is the reference method, comparative studies of liver volume measurement using ultrasonography, along with our corrected method, should be considered mandatory.

References


