The performance of three-dimensional ultrasound reconstruction of the bile ducts in the diagnosis and assessment of extrahepatic cholestasis – a clinical trial on 48 patients

M. Socaciu¹, R. Badea¹, M. Tanţău², C. Iancu³, Simona Tripon¹, C. Caraiani¹

¹ - Dept. Ultrasonography, 3rd Medical Clinic, Cluj-Napoca
² - Dept. Endoscopy, 3rd Medical Clinic, Cluj-Napoca
³ - 3rd Surgical Clinic, Cluj-Napoca

Abstract

Aim. The assessment of three-dimensional (3D) ultrasound reconstructions using the transparent and the inverse mode for the diagnosis and description of obstructive jaundice of various etiologies.

Material and Method. 48 patients with bile ducts dilations, most of them documented by retrograde endoscopic cholangiography (43/48) and 9 control subjects without bile duct pathology. 3D ultrasound followed conventional 2D examination and the examination protocol included an image algorithm based on the transparent and inverse modes. The 2D and 3D techniques were compared in order to evidence the diagnostic value and final relevance of the image.

Results. The biliary tree was visualized by 2D ultrasound in 6 control subjects and by 3D in 4 subjects, the images being relevant in 8 patients with 2D and in 4 with 3D respectively. In the obstructive jaundice group the bile ducts dilations were visualized by 2D in 89.6% of the patients and by 3D in 86.5%. Cholestasis was confirmed in 77.1% of the cases after 2DUS examination and in 79.2% of the cases after 3D reconstructions. The cause of biliary obstruction has been determined using 2D US in 38 of the 43 patients also explored by ERCP, the sensitivity being 55.8% for 3D reconstructions. The reconstruction mode with the best results was “transparency” mode, although for upper obstructions the “surface” mode was more successful. The average duration for the first acquisition was 1min 42s.

Conclusion. 3D ultrasound in the transparent mode combined with inverse mode allows the identification of the dilated bile ducts and the level of the obstruction. The method does not allow the establishment of the cause of the obstruction and does not provide information on the tumoral features. The 3D image is relevant and illustrative of the amplitude of the biliary dilations, which contributes to the reliability of the diagnosis obtained by 2D ultrasound.

Key words: 3D ultrasound, extrahepatic cholestasis, retrograde endoscopic cholangiography
Introduction

Obstructive jaundice constitutes one of the main indications of abdominal ultrasound, due to the relatively good performance of the method in the detection of biliary dilations (Se = 72-80%, Sp = 86-90%) and the average performance in the detection of the cause of obstruction (Se = 65%) [1, 2]. While being highly cost-effective, abdominal ultrasound can also be easily accessed and repeated as often as needed, thanks to its non-radiating and non-invasive nature. Depending on the availability of other diagnostic methods, ultrasound is combined with more effective non-invasive investigations, in the first place cholangio-MRI (which provides highly accurate information on the whole biliary tree, with the visualization of Vater’s papilla), as well as retrograde endoscopic cholangiography (an invasive method considered to be the gold standard having a diagnostic and therapeutic value) [3].

One issue that must be emphasized is the fact that much of the performance of ultrasound is closely linked to the experience and practical knowledge of the operator [4]. Furthermore, as opposed to other radiological procedures, one can not do a whole body or even a whole organ scanning using ultrasound. The stored images are not reliable enough for an “offline” examination, as they might not cover sufficient anatomical volume. This is where the automatic 3D US scanning (using a dedicated 3D probe) might bring a true benefit. Even though the scanned volume is still limited, one has the certainty that inside it there is ultrasound information from each section, directly comparable with the underlying anatomy. If some structures offer enough contrast, they can be seen through the volume (“transparency mode”) or subtracted from the volume (“surface mode”), which is the case of the dilated bile ducts (anechoic) inside or even outside the liver. The aim of this trial was to assess the utility, the limits and possible clinical applications of 3D ultrasound in obstructive jaundices.

Material

The clinical trial was carried out in the Ultrasound Department of the Medical Clinic III, Cluj-Napoca, Romania, on a group of 48 patients with already diagnosed and documented biliary obstructive diseases (based on clinical and biochemical tests) and a control group of 9 subjects clinically and biochemically disease-free. Most of the patients (43/48) had been already submitted to an endoscopic retrograde cholangio-pancreatography (ERCP), which was considered the trial’s golden standard.

The equipment consisted in a General Electric Logiq7 ultrasound machine (software revision R6.0.3, updated with Basic and Advanced 3D software modules). For the 2D examination we used a GE 4C probe (with a variable frequency between 2-7 MHz), while for the 3D acquisition we used a dedicated 3D convex probe (GE 4D3C-L), with variable frequency between 2-5 MHz and automatic mechanic sweeping. Both probes were used with coded harmonic imaging (CHI) activated for optimal contrast. The acquired data was stored on the ultrasound machine’s hard disk in RAW-DICOM format, which enables the post-processing of the 3D volume at any time and has no informational loss compared to the original electromagnetic data. Post-processing of that data was performed on the machine either immediately after acquiring or at a later time (outside examining hours). For later assessing and presentation, RAW-DICOM data was transferred on a PC and converted in bitmap format using eFilm 2.0.0.

Methods

Study design. The study consisted in a prospective, longitudinal, case-controlled clinical trial. Due to the low number of cases and heterogeneity of the group we only used descriptive statistics. The patients were recruited based on their clinical and biochemical alterations suggesting an obstructive jaundice. The inclusion criteria were the medically documented biliary obstruction and the patient’s consent. The exclusion criteria were a poor general state of the patient, preventing him from sustaining an apnea for 10s, low level of consciousness and the refusal of consent. For comparison purposes we also had 9 control subjects, clinically and biochemically disease-free. All the examinations were performed by one physician with over 15 years of experience in the ultrasonographic practice. The images were then blindly assessed by another physician and all the criteria below mentioned were than taken into consideration. A comparison was made between the images obtained through 2D ultrasonography (2DUS), 3D ultrasonography (3DUS) and ERCP.

The 2D ultrasound examination was performed using as an ultrasound window the right hypocondrium and the intercostal spaces, the patient being asked to remain in apnea for a convenient period of time, in order to ensure an examination as complete and accurate as possible. All the patients were examined in fasting conditions and before noon, to avoid as much as possible air and food artifacts.

The 3D ultrasound examination immediately followed the 2D exploration, being intended for the intrahepatic (right, left, hilum) and extrahepatic ducts (the whole common bile duct). The gallbladder was included in the scanned volume, being used as a guide mark to certify the right position of the “region of interest” (ROI) over the hepatic hilum.

The technique of sampling and processing of the volume involved several steps: a) selection of the area of
interest in 2D mode, obtained in a sagittal section along the right midclavicular line (lateral movement responsible for movement artifacts is weaker than the vertical movement); special care was taken to avoid air and rib shadows; b) adjustment of the ROI in order to cover a minimum sized volume, but still large enough for the whole biliary tree to be included; the sweep angle was set at ±45 degrees (not too small, to include more tissue but not too large, to have a better line density); the “quality” value was set to “Mid” to have an acceptable level of line density while still performing a quick sweep, thus avoiding movement artifacts; c) setting of the equipment for the static 3D mode; d) acquisition of the volume (during the acquisition, the patient remained in apnea for a total duration no longer than 10 seconds); e) processing of the information obtained in the volume using the multiplanar mode with the positioning of the area of maximum interest in the center of the image; f) correction of the spatial position of the area of interest and its orientation in an anatomical position; g) use of the transparent mode, and then, of the inverse mode; h) processing of the reference sections and the reconstructed volume using the correction of the adjusting of “gain” and “lower threshold” until the exclusion of most of the parenchymal data and the preserving of transonic data (ductal and vascular, appearing bright due to inversion mode); “lower threshold” could be set between 0 and 255 luminosity units, with increments of 5, while “gain” was adjusted at a level where no echoes could be found inside the ducts; i) change from the multiplanar function to the single volume function; j) evaluation of the volume using rotations in latero-lateral and cranio-caudal directions and processing for an as good as possible visualization of the bile ducts in terms of spatial position, anatomic pathway, definition of dilation and identification of the obstruction.

In order to assess the information, the following were taken into consideration: 1. confirmation of bile ducts dilation (existence of parallel / extrahepatic ductal structures that achieve the sign of the “double duct”); unfortunately, the ultrasound machine in use does not provide the option of measuring items on 3D reconstructed images, hence the impossibility of a comparison between bile ducts’ caliber in 2D and 3D images; 2. identification and definition of the obstruction; 3. relevance of the ultrasound image (visibility and evidence of the bile ducts, gallbladder and the neighboring structures, with the aim of increasing the reliability of the US image both for the main examiner and for a second examiner, possibly a surgeon).

The assessment was performed based on the absence / presence of items (1) and (2), and on a scale comprised of: “very good”, “good” and “poor”, for item (3) (see table 1).

### Table 1. The relevance scale in assessing bile ducts image quality

<table>
<thead>
<tr>
<th>Relevance scale</th>
<th>Image characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>Whole biliary tree visible; well defined border delineation; no artifacts</td>
</tr>
<tr>
<td>Good</td>
<td>Whole biliary tree visible; partially flawed border delineation ± artifacts</td>
</tr>
<tr>
<td>Poor</td>
<td>Parts of the biliary tree not included; unclear border delineation; severe artifacts</td>
</tr>
</tbody>
</table>

### Results

The performance of the 2D and 3D ultrasound in the diagnosis and description of extrahepatic cholestasis (48 patients) was assessed in relation with the site of the obstruction, relative to the insertion of the cystic duct into the common bile duct and to the papilla. As a result, there were upper biliary obstructions (above the level of cystic duct insertion), middle biliary obstructions (under the level of cystic duct insertion and above the papilla) and lower biliary obstructions (at the level of the papilla).

Out of the total of 16 patients with upper biliary obstruction, 10 had hilar cholangiocarcinomas, 1 had a ductal cholangiocarcinoma, 3 had cysts of the common bile duct and 2 were cases of intrahepatic lithiasis (fig.1-3).

The subgroup of middle biliary obstruction had 22 cases: 17 with common duct lithiasis, 1 choledochal tumor, 1 with choledochal sludge, 1 infrahepatic hydatid cyst and 2 common duct dilations of unknown cause (fig.4).

Among the 10 patients with lower biliary obstruction there were: 7 pancreatic head tumors, 2 ampullomas and 1 inferior choledochal tumor (fig.5).

In the control group (9 patients) the following results were obtained: 2D US revealed the intra- and extra-hepatic bile ducts and the gallbladder in 6 (66.7%) cases; image relevance was “very good” in 8 (88.9%) and “good” in one case (11.1%); 3D US revealed the intra- and extra-hepatic bile ducts in 4 (44.4%) cases (gallbladder was evidenced in all the cases), with a “very good” image relevance in 4 (44.4%) cases, “good” in 3 (33.3%) cases and “poor” in 2 (22.2%) cases.

The common bile duct was visible in 89.6% of 2D images and 87.5% of 3D images from the patients with obstructive jaundice (compared to 77.8% of 2D and 44.4% of 3D images from control subjects) (fig.6). The elements from the hepatic hilum were visible in 97.9% of 2D images and 95.8% of 3D images from the patients with obstructive jaundice (compared to 88.9% of 2D and 66.7% of 3D images from control subjects) (fig.7).

The relevance of 2D images for the cases with biliary obstruction was “very good” in 52.5% and “good” in 37.5% of cases, while the relevance of 3D reconstructions
was “very good” in 45.8%, “good” in 47.9% and “poor” in 6.3% of cases. The distribution of the relevance of 2D and 3D images according to the level of obstruction is seen in fig.8. For 2D images, the best relevance corresponded to lower obstructions, while, for 3D images, middle obstructions had the best relevance.

Cholestasis was confirmed in 77.1% of the cases after 2DUS examination and in 79.2% of the cases after 3D reconstructions (fig.9). In 1 case (2.1%) there were no biliary ducts dilations on ERCP, nor on 2D and 3D US. The sensitivity in diagnosing duct dilations (using ERCP as a standard) was 78.7% for 2DUS and 80.8% for 3DUS.

The cause of biliary obstruction was determined using 2D US in 38 of the 43 patients also explored by ERCP (88.3%), the sensitivity relative to ERCP being 92.6%. For US 3D, the cause of obstruction was determined in 24 of the 43 cases with ERCP (55.8), the sensitivity relative to ERCP being 58.5% (fig.10a). The best results in determining the cause of obstruction were obtained for 2D US in lower obstructions (100%) and for 3DUS in upper obstructions (56.3%) (fig.10b). Similar findings were obtained in the assessment of the level of obstruction, the extension and the nature of obstruction.

Fig.1. Hilar cholangiocarcinoma (Klatskin tumor); a) 2D sonogram revealing the dilated hepatic ducts and the space occupied by the tumor; b) ERCP image diagnostic for biliary obstruction; c) 3D reconstruction in “surface” mode + “inversion”; d) 3D reconstruction in “transparent” mode + “inversion”, better depicting the tumor delineation.
Fig. 2. Common bile duct (CBD) cyst; a) 2D sonogram showing the location, relations and dimension of the CBD cyst; b) 3D reconstruction in “surface” mode + “inversion” (“vb” = gall bladder, “chistic” = cystic duct, “vp” = portal vein); c) ERCP showing the communication with the CBD; d) intraoperative situation.

Fig. 3. Right duct cholangiocarcinoma; a) 2D sonogram in B + B-Flow mode revealing the localized dilation of the bile duct and the mass effect of the tumor; b) 3D reconstruction in “transparent” mode + “inversion” offers a better spatial localization of the tumor.
Common bile duct lithiasis; a) 2D sonogram shows the dilated bile duct and the hypechoic image of the calculus with strong posterior attenuation; b) 3D reconstruction in “surface” mode + “inversion” of the dilated bile ducts; c) 3D reconstruction in “transparency” mode + “inversion” showing the print of the calculus cast in the image of the duct; d) lacunar image produced by the calculus in the dilated biliary duct (“surface” + “inversion”).

Moderate common bile duct dilation produced by a pancreatic head tumor; visualization of the anatomy of the hilum; a) 3D reconstruction in “transparent” mode + “inversion”; b) 3D reconstruction in “surface” mode + “inversion” (“vb”=gall bladder, “vp”=portal vein, “vps”=left portal vein, “vpd”=right portal vein, “cbp”=common bile duct).
In all 3D reconstructions we used the “inversion” function combined with both “transparency” and “surface” modes. Globally the best relevance was obtained from images in “transparency” mode (28 cases – 58.3%) than...
"surface" mode (20 cases – 41.7%). However, in the upper obstructions, the "surface" mode was more useful (68.8%), while in the other two subgroups the "transparency" mode was more successful (fig.11).

The time spent for the first 3D reconstruction in one patient is depicted in fig.12 as scattered points. The mean value was of 1 min 42 s. The longest duration was for the patients with lower bile duct obstruction (2 min 3 s) (fig.12b).

Discussion

The technological improvements of the past 10 years, such as the development of spatial representation programs, the use of extremely fast processors and the construction of specialized transducers with simultaneous two-dimensional scanning, have led to the achievement and implementation of the three-dimensional (3D) technique in ultrasound [5].

The quality of the obtained 3D images depends on the global dimension of the scanned area, the scanning angle, the tissue depth at which scanning is performed and the accuracy of the image. The method consists of the selection of an area of interest called reference section that should be a 2D ultrasound with as good a quality as possible; the final ultrasound volume will be centered by this reference area and will consist of an equal number of planes situated on both sides of it.

For the moment, most 3D ultrasound applications are gynecologic and obstetric [6, 7]. Recently, studies have shown that this method can also be useful in abdominal pathology [5, 8]. This category includes the applications used for the assessment of functional and morphological pathology (especially tumor staging) in digestive tract diseases [9, 10].

In liver pathology, 3D ultrasound can detect aspects related to the presence and extension of parenchymal restructuring in cirrhosis [11]. Using CT-like techniques, tumors up to 10 mm in size can be accurately detected (provided that they are not isoechoic) and information can be obtained on their position, in relation to the reference vessels: hepatic veins, portal veins, and inferior vena cava as well as the real size of the tumor mass. Oncological safety elements can be added, allowing the surgeons to assess the volume of tissue to be removed, particularly in techniques like radiofrequency ablation or percutaneous alcoholization [12]. Contrast enhanced vascular 3D ultra-
sound can better characterize spatial distribution, vascular architecture, as well as the type of tumor vascularization, allowing the identification of specific vascular models, in a manner similar to angiographic techniques [13].

The exploration of the gallbladder and bile ducts represents a new challenge for 3D ultrasound. The performance of conventional 2D ultrasound for the evaluation of biliary pathology is well known, this being the first imaging technique carried out in the sick patient, depending on which subsequent investigations are performed. The method has well-known limitations, among which the fact that it depends on the examiner and the relevance of the diagnostic image varies according to the mode in which it has been obtained [14].

It is extremely useful, for surgeons in particular, to understand the spatial position of a structure at the level of the biliary tree in relation to the hepatic segmentation. The operative strategy and the final results often depend on this component.

Three-dimensional ultrasound allows the spatial representation of anatomic structures and facilitates, by means of special software, the spatial rotation of the volume and a “cutting-out” within it. The best known 3D application at the level of bile ducts is the transparent mode (fig.5 a) which allows the visualization of the bile ducts within the hepatic parenchyma [15]. However, the 3D examination of the bile ducts in this mode is rather difficult because of the similarity between vascular structures and biliary structures, which cannot be differentiated one from another. The hepatic texture that is “molded” on the bile ducts adds to this difficulty.

Three-dimensional ultrasound using the transparent mode can be optimized using the inverse mode (fig.5), which eliminates these inconveniences and may be considered a technical advancement. Thus, the bile ducts and the hepatic vessels are seen much more distinctly and the surrounding hepatic parenchyma is practically eliminated from the image, which makes the investigation considerably easier.

The bile ducts and the hepatic vessels can be relatively easily differentiated by the rotation of the volume around the longitudinal axis, which allows their dissociation. In addition, the rotation of the volume around a transverse axis allows the exploration of the hepatic hilum, the examination being similar to the intraoperative macroscopic examination.

The visibility of the biliaryducts in 3DUS was in our study marginally lower than in 2D US, which was to be expected. (fig.6, 7) However, when visible, 3D images offer more information and have more impact on the understanding of spatial relations. Normal bile ducts are better viewed inside the liver, over shorter distances. Depending on the patient’s status, very convincing images of the gallbladder (shape, size, presence of anomalies) and of the intra/extrahepatic bile ducts could be obtained. A predictable application of 3D ultrasound of normal bile ducts is a better understanding and illustration of biliary anomalies (anatomic variants or malformations).

The diagnostic performance of 3D ultrasound increases when the bile ducts are dilated (the control group provided less visibility than the case group). The explanation is that ectatic ducts are easier to reveal using the transparent and inverse mode software. The best known application of this method is the characterization of biliary cysts whose spatial distribution is extremely easy to depict [16] (fig.2 b).

In assessing the presence of cholestasis, the performance of US3D is slightly better than that of US2D and quite close to ERCP (Se=80.8%). Its sensitivity increased slightly due to the lessening of the cases with uncertain cholestasis, compared to 2DUS (fig.9).

When it comes to the assessment of the obstruction’s cause, three-dimensional ultrasound of the bile ducts does not have the same diagnostic value as 2D ultrasound (fig.10), being in fact complementary to the latter. The golden standard was considered the endoscopic retrograde cholangio-pancreatography (ERCP), which was performed in 43 out of 48 cases. The low sensitivity of 3DUS (56.3%) can be explained by its lesser differentiation of tissue types due to the alteration of echogenicity levels in the reconstructed image. However, this information is not lost when the representation of the 3D volume is sectional. The diagnosis of biliary lithiasis (based on lacunar images inside the ducts – fig.4 d) and the detection of small sized tumors are limited by the still unsatisfactory accuracy of the method. The best results of 3D reconstructions were achieved in upper biliary obstructions. The spatial disposition of the bile ducts is more eloquent and the distance between the hepatic ducts in the case of a Klatskin tumor is easier to assess by this technique (fig.1). In addition, the investigation of the ampullary region is extremely difficult, the technique being subject to the main limits of ultrasound: meteorism, obesity, lack of cooperation.

The most appropriate reconstruction mode differs according to the pathological substrate and what we might expect from an image: to offer a general view as complete as possible, for instance in screening (“transparency” mode) (fig.5 a) or the rendering in space of a local detail as realistic as possible (“surface” mode) (fig.5 b). Generally, the transparency mode was more useful, thanks to its fewer artifacts and texture alterations produced through processing. In upper obstructions, due to the good contrast offered by the liver parenchyma, the “surface” mode (combined...
with the “inversion” function) has offered the best images of intrahepatic bile ducts (fig. 11).

One last aspect studied here was the duration of the examination (fig. 12 a, b). The acquiring of the first 3D volume for a patient takes most of the time, as it requires the fine tuning of all 3D parameters. Subsequent acquisitions take only several seconds. Compared to the duration of an abdominal sonography, the average time of 1 min 41 s does not represent a lot, keeping in mind that there is a lot of acquired ultrasound information that is accessible for a later review (also in sectional mode).

The main contribution of the 3D technique is the image relevance for the examiner (increasing confidence in diagnosis) as well as for the surgeon. The use of “cut-out” software in association with the change of image algorithms such as “threshold” could bring the 3D ultrasound image closer to MRI cholangiography, allowing, at the same time, the navigation within the biliary tree in a similar manner to CT cholangioscopy [17].

The introduction of this technique into the clinical practice is relatively recent. More extensive studies over a longer period of time and on larger patient groups are expected in order to assess its usefulness in routine examinations.

Conclusion

Three-dimensional ultrasound represents a complementary technique to conventional 2D ultrasound, as it provides a spatial representation of the bile ducts and the gallbladder. Inversion mode represents an improvement of the 3D ultrasound image in the description of the dilated biliary tree. The diagnostic value of the technique is represented by the confirmation of bile duct dilations, the identification of the site of the obstruction and the better visualization of the cystic formations. The method does not allow the establishment of the cause of the obstruction and does not provide information on the tumor features. The method is highly illustrative and it considerably increases the confidence in diagnosis.

References