Volume imaging for your ultrasound department

Practical guide to getting started

This booklet provides clinicians with an easy-to-follow guide on both why and how to integrate volume imaging into your ultrasound labs. The results of a recent survey at six European sites provide compelling data on the impact volume imaging has had on improving the diagnostic results of their ultrasound departments. Each site was asked to complete 50 ultrasound exams using first 2D only, followed by a volume exam.
Below is a summary of results from a Philips European volume imaging survey. The key objective was to measure the impact of volume imaging on the ultrasound applications listed. Each site was asked to complete 50 studies and answer a series of “yes” or “no” questions. The percentages reflect the number of “yes” answers to the questions.

### Results from European study – 343 cases

<table>
<thead>
<tr>
<th>Application</th>
<th>Clinician and Location</th>
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| Liver       | Etienne Danse, MD, PhD and Mohamed Kichouh, sonographer  
37 cases | St. Luc University Hospital, Université Catholique de Louvain, UCL – Brussels, Belgium |
| Renal       | Simon T. Elliott, MD  
50 cases | Freeman Hospital – Newcastle Upon Tyne, UK |
| Gyn         | Giovanni Serafini, MD and Luca M. Sconfienza, MD  
29 cases | Radiology Unit, Santa Corona Hospital – Pietra Ligure, Italy |
| Breast      | Ariel Saracco, MD  
55 cases | Bröstcentrum SöS – Stockholm, Sweden |
| Bowel       | Etienne Danse, MD, PhD and Mohamed Kichouh, sonographer  
18 cases | St. Luc University Hospital, Université Catholique de Louvain, UCL – Brussels, Belgium |
| Peds/Misc   | Michel Claudon, MD and M. Galloy, MD  
55 cases | Centre Hospitalier Universitaire – Nancy, France |
| Renal       | J.M. Correas, MD and A.M. Tissier, MD  
49 cases | Necker University Hospital – Paris, France |
| Renal with contrast | J.M. Correas, MD and A.M. Tissier, MD  
50 cases | Necker University Hospital – Paris, France |

### Additional information increased confidence

- Liver: 85%
- Renal: 94%
- Renal: 2%
- Renal/Contrast: 26%
- Gyn: 62%
- Breast: 18%
- Bowel: 78%
- Peds/Misc: 93%
- TOTAL: 57%

### Virtual rescanning improved surveillance or audit

- Liver: 87%
- Renal: 98%
- Renal: 80%
- Renal/Contrast: 90%
- Gyn: 24%
- Breast: 89%
- Bowel: 80%
- Peds/Misc: 80%
- TOTAL: 73%

### Changed diagnosis

- Liver: 70%
- Renal: 16%
- Renal: 67%
- Renal/Contrast: 4%
- Gyn: 62%
- Breast: 67%
- Bowel: 67%
- Peds/Misc: 80%
- TOTAL: 29%

### Increased confidence in lesion localization

- Liver: 90%
- Renal: 34%
- Renal: 55%
- Renal/Contrast: 72%
- Gyn: 28%
- Breast: 75%
- Bowel: 75%
- Peds/Misc: 4%
- TOTAL: 53%

### Increased confidence in lesion vascular anatomy

- Liver: 87%
- Renal: 8%
- Renal: 55%
- Renal/Contrast: 78%
- Gyn: 48%
- Breast: 75%
- Bowel: 75%
- Peds/Misc: 24%
- TOTAL: 50%

### Improved communication to referring physician

- Liver: 69%
- Renal: 37%
- Renal: 76%
- Renal/Contrast: 88%
- Gyn: 41%
- Breast: N/A
- Bowel: 48%
- Peds/Misc: 48%
- TOTAL: 65%

### Changed imaging strategy

- Liver: 73%
- Renal: 82%
- Renal: 4%
- Renal/Contrast: 88%
- Gyn: 48%
- Breast: 50%
- Bowel: 28%
- Peds/Misc: 71%
- TOTAL: 45%

### Improved exam efficiency and shortened exam time

- Liver: 91%
- Renal: 82%
- Renal: 0%
- Renal/Contrast: 88%
- Gyn: 48%
- Breast: 0%
- Bowel: 73%
- Peds/Misc: 75%
- TOTAL: 88%

### Facilitated measurements

- Liver: 75%
- Renal: 80%
- Renal: 71%
- Renal/Contrast: 88%
- Gyn: 45%
- Breast: 66%
- Bowel: 57%
- Peds/Misc: 75%
- TOTAL: 71%
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1. Volume imaging of an abdominal aortic aneurysm

Simon T. Elliott, MD
Freeman Hospital, Newcastle upon Tyne, UK

Key reasons to consider 2D plus volume imaging approach
Surveillance scanning of abdominal aortic aneurysm (AAA) requires meticulous attention to measurement detail in order to reduce inter-observer variation over time. Volume ultrasound provides a fast and efficient method of examination and security of imaging data, so that sequential examinations can be stored, reviewed and compared.

We have shown that AAA measurements made using volume ultrasound are at least as accurate as conventional 2D scanning, and volume ultrasound offers significant advantages in terms of imaginative workflow processes.

How we do the exam
The volume ultrasound examination is based on our standard 2D AAA protocol. This consists of the mean of two sagittal, anteroposterior (AP) maximum diameters and the mean of two coronal transverse (TS) maximum diameters.

Anteroposterior
1. Place the volume transducer over the midline of the AAA in the sagittal plane (Figure 1).
2. Optimize the image (for example, using iSCAN, compression and harmonic).
3. Enter 3D/4D mode from the touchscreen.
4. Set sweep angle. (Since you are only interested in maximum diameter this is usually 30 to 40 degrees. Reduce the angle and you reduce movement artifact.)
5. Ask the patient to stop breathing, and press Update. The system will freeze automatically at the end of the sweep.
6. If you are happy with the acquisition, press Save 3D Volume. If not, repeat a. through e.

Coronal transverse
1. Place the transducer on the left side of the abdomen to approach the AAA as close to true coronal plane as possible (Figure 2).
2. Follow b. through f. as for AP acquisition.

With practice and increasing confidence, you may now find that the patient can leave the examination room. All the measurements can be made from the stored data, on cart or off cart, using QLAB quantification or ViewForum.

Measurement (AP and TS)
1. Open the saved volume data sets, from Review in MPR tab.
2. Measurements will be made from Frame 1, which can be maximized or zoomed to improve caliper placement accuracy.
3. Simply use the Slice rotary control to identify the maximum AAA diameter.
4. Measure AAA diameter using calipers.
5. You may wish to repeat 3 and 4 to take the mean of measurements.

Figure 1
Figure 2

Clinical impact of new volume imaging approach

- Volume ultrasound data sets can be acquired in all patients where 2D imaging of AAA is possible.
- For both AP and TS diameters, there is no significant difference between conventional 2D and volume measurement methods.
- Examination time for volume ultrasound is significantly reduced (as low as 90 seconds).
- Measurement can be “time and place shifted” away from the examination table. For example, in our one-stop AAA clinic, measurements can be made off cart while the patient is returning to see the surgeon, and while the next patient is being scanned. This leads to significant benefits for workflow efficiency.
- Volume data sets are stored for audit and clinical review at next attendance, just as in CT and MR imaging.

Case study

A typical example of an AAA surveillance scan using volume acquisition ultrasound.

A 70-year-old female patient with a 4.5 cm infrarenal AAA, undergoing six-monthly surveillance. The previous scans, using conventional 2D method, showed an average examination time (to assess aortic diameter) of approximately five minutes. The volume acquisition method involved an examination time of less than 90 seconds. The measurement was then made from the volume data set, while the patient returned to the referring surgical clinic. The results were typed directly into the RIS system and available to the surgeon immediately.

This practice of using volume ultrasound has led us to redesign our workflow and improve efficiency. In addition, the data sets can be stored for review of measurement technique and caliper placement, particularly for difficult aneurysm configurations, such as a tortuous aorta. This practice further reduces inter-observer variations in surveillance scanning.
2. Volume imaging of the gallbladder

Simon T Elliott, MD
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Key reasons to consider 2D plus volume imaging approach
Ultrasound is the first-line imaging modality for suspected gallbladder (GB) pathology. Conventional 2D ultrasound requires meticulous attention to coverage of the whole of the GB using individual, user-selected slice planes. Only those planes are stored for review or second reading.

Volume ultrasound enables capture of the whole of the GB in one or two short sweeps. As in CT and MRI, the dataset can then be reviewed in several planes. The size, location and high tissue-contrast nature of the GB lends itself to this method.

In our unit\(^2\) we have recently shown that volume ultrasound of the GB, using two data sets (supine and decubitus) is as accurate as conventional 2D ultrasound for a range of pathologies, but offers significant advantages in terms of review, audit and time saving. In addition, GB function studies can be performed using volume ultrasound, with greater volumetric accuracy and with much greater efficiency.

How we do the exam
The volume ultrasound examination consists of two sweeps of the GB patient in supine and in left decubitus positions. For both positions the acquisition technique is the same.

1. Using the V6-2 transducer, locate the GB as for conventional 2D scanning.
2. Optimize the image for size, tissue contrast (for example, using harmonics) and resolution (Res/Gen/Pen). Use the highest resolution possible.
3. Align the A-plane (the basic 2D scan plane) with the midline of the long axis of GB, usually from the neck to the fundus.
4. Select 3D/4D menu. You may wish to use the ROI function in this menu to concentrate the sweep to the GB only.
5. Select an appropriate sweep angle. This angle will depend on the size and depth of the GB in each patient, but is usually around 40 degrees.
6. In suspended respiration, start 3D sweep. During the sweep you will be able to see if the entire GB has been included in the dataset. If not, repeat using a larger sweep angle. (Note that the larger the angle, the slower the sweep and the more chance of motion artifact.)
7. Press Save 3D Volume to store.
8. Review data using MPR.
9. Volume rendering mode and QLAB iSlice provide good presentational tools to the referring clinician.

Clinical impact of new volume imaging approach
• Volume ultrasound of the GB can be performed in almost all patients in whom conventional 2D ultrasound is possible.
• Volume ultrasound acquisition is quicker than 2D, leading to efficiency gains.
• Volume ultrasound of the GB can be used as a stand-alone technique for assessing common GB pathologies, such as calculus, clinically significant polyps and cholecystitis.
• The stored dataset provides a permanent record of the entire organ, for second reading, review or audit.

Case study

A 72-year-old male presented with epigastric pain. Conventional 2D ultrasound diagnosed the presence of a small gallbladder polyp. Volume ultrasound confirmed the presence of a single polypoid lesion on the A-plane, but unlike typical gallbladder polyps this was not reproduced on other planes. By using MPR iSlice function, it was suspected that this lesion actually represented a cross section of a linear mucosal structure in the gallbladder. Volume rendering was performed to confirm the presence of a mucosal fold, and that no polyp was present. All this image manipulation was performed, and the final diagnosis made, after the patient had left the examination room, at the time of second reading of the scans.

Image A. 2D A-plane scan suggesting gallbladder polyp.

Image B. Volume render showing mucosal fold (arrow).

Image C. Volume render showing mucosal fold (arrow).
3. Volume imaging of the gallbladder
Nitin Chaubal, MD
Thane Ultrasound Centre, Thane, Maharashtra, India

Key reasons to consider 2D plus volume imaging approach
In the era of laparoscopic surgery, images of gallbladder pathologies obtained in conventional single planes on ultrasound may provide inadequate information for a surgeon. Ultrasound volumetric imaging for gallbladder has the potential to provide accurate information of gallbladder pathologies both in terms of nature and location of the lesion.

Functional studies of the gallbladder were previously done with 2D ultrasound, providing only rough measurements. Estimation of volume with the 2D technique has serious limitations, depending on the shape of the gallbladder. Volumetric measurement gives more exact volume in pre- and post-prandial status and, hence, is a more accurate way of studying gallbladder function.

Gallbladder volume and wall thickness are also clinically important in deciding the nature of surgery: laparoscopic vs. open. These measurements are now possible with volumetric imaging.

The advantages of volumetric imaging include the abilities to quickly obtain data, store, retrieve, and manipulate it at a later date and at a different site.

How we do the exam
1. Exams are done in fasting state using a V6-2 probe. Studies are also done after a fatty meal to study post-prandial contraction.
2. Volume sweeps of the gallbladder are taken with patient in decubitus position.
3. Gallbladder is imaged along its longitudinal axis with optimized grayscale and region of interest.
4. Sweeps are also obtained in supine position. (For a few patients in the study, data was obtained with the patient in sitting position.)
5. Once entire gall bladder is included in the dataset, data is stored with 3D volume store.
6. A majority of calculations and reviews can be done afterwards on the ultrasound system and offline using QLAB quantification software on a laptop.

Clinical impact of new volume imaging approach
• Referring clinicians were most impressed with the images and virtual tour of the gallbladder. Moreover, volume imaging helped them in making clinical decisions regarding management and type of surgical approach.
• Functional studies were accurate and useful.
• Studies were timesaving, allowing the ability to review data at later date.
• Difficult regions of gallbladder were studied with ease.
**Case study**

A 24-year-old male patient presented with vague abdominal pain. A 2D ultrasound revealed a normal appearing gallbladder with an adjacent part showing thick walls with sludge and calculi. The impression was that of a septate gallbladder.

Volume sweeps of the gallbladder with the V6-2 probe with 3D reconstruction demonstrated two distinct gallbladder lumens with separate walls. The images were suggestive of a duplication of gallbladder; this possibility was suggested in the report. Surgery confirmed a duplication of gallbladder, a rare entity. One was normal and the other showed thick walls with sludge and calculi.

Volumetric imaging of the gallbladder helped make this difficult diagnosis. Moreover, this diagnosis was made at the time of reporting, after the patient had left the clinic.
4. Volume imaging of the kidney
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**Key reasons to consider 2D plus volume imaging approach**

Ultrasound is a first-line imaging modality for suspected renal pathology. Volume ultrasound can capture the whole of both kidneys in the majority of patients. The data set can be stored for second reading, and reviewed in several planes, as with CT and MRI. Ultrasound image planes that are impossible to obtain using 2D imaging can be produced.

Rotation of the volume data around set pivot points allows a systematic assessment of the renal architecture, particularly the collecting system. Surveillance of renal lesions, such as complex cysts, is improved due to permanent storage of the volume data set, and the high spatial resolution provided by ultrasound.

Volume ultrasound appears to be a more robust and accurate method of measuring renal length.

**How we do the exam**

Volume ultrasound acquisition is based on the conventional 2D longitudinal view of each kidney. In order to reduce motion artifact and improve visualization of the entire kidney, volume sweeps should be performed in full and suspended inspiration.

1. Using the V6-2 transducer, locate the kidney as for conventional 2D scanning.
2. Optimize the image for size, tissue contrast (for example, using harmonics) and resolution (Res/Gen/Pen). Use the highest resolution possible.
3. Align the A-plane (the basic 2D scan plane) with the midline of the long axis of kidney from pole to pole.
4. Select 3D/4D menu. You may wish to use the ROI function in this menu to concentrate the sweep to a specific region of the kidney.
5. Select an appropriate sweep angle. This will depend on the size and depth of the kidney in each patient, but is usually around 40 degrees.
6. In suspended respiration, start 3D sweep. During the sweep you will be able to see if the entire target has been included in the data set. If not, repeat using a larger sweep angle. (Note that the larger the angle, the slower the sweep and the more chance of motion artifact.)
7. Press Save 3D Volume to store.
8. Review data using MPR.

**Measure renal length**

1. Acquire as above.
2. In MPR mode, use the A-plane (which should be displaying the longitudinal view of the kidney) for adjustment and measurement.
3. Rotate Z-axis control until the kidney lies roughly horizontal on the image.
4. Rotate the Slice control until you can clearly define the lower pole of the kidney.
5. Drag the MPR crosshair to the tip of the lower pole. Rotate the kidney image around this point by turning the Y-axis control, until the maximum renal length is displayed.
6. Measure the renal length, pole to pole, using conventional calipers.

**Clinical impact of new volume imaging approach**

- The stored volume data set provides a permanent record of the kidney or focal lesion, for second reading, review, or audit. This is particularly useful for surveillance scanning.
- Volume ultrasound offers a more systematic and controlled review of renal architecture.
- Measurement of renal length is more robust and potentially more accurate.
Case study
A 31-year-old male patient with a previous history of matrix renal calculi, attended for ultrasound examination of the kidneys. 2D ultrasound showed a normal left kidney and a mild right hydrenephrosis. Definition of the collecting system was, however, poor (Image A), and there was the suggestion of a matrix calculus within the lower pole calyces (Image B). A single volume acquisition scan was performed on the right kidney. By placing the MPR crosshair over the renal pelvis, and rotating around this pivot point using the Y-axis control, it was possible to interrogate systematically each part of the collecting system (Images C and D).

The views obtained were significantly better than using 2D ultrasound, enabling the operator and second reader to confirm that, other than the mild hydrenephrosis, the kidney was normal and that no renal calculus was present.
Key reasons to consider 2D plus volume imaging approach

Volume measurements of kidneys have potential benefits in nephrology. As compared to linear measurements on 2D, volume is more useful and accurate in following up patients.

Volume measurement of transplanted kidneys on a baseline scan is also useful in picking up early rejection.

Volume ultrasound gives anatomical details of the pelvicalyceal system as never seen before; this has potential for evaluating intrinsic lesions in the collecting system.

Volume imaging with power Doppler or contrast has the potential to demonstrate the exact relationship of tumors with surrounding vessels, which is useful in planning organ-saving surgery.

Reconstruction and measurements can be performed offline and data stored.

How we do the exam

Examination is performed with patient in lateral decubitus position, using the right lobe of liver as a window on the right side.

1. Using the V6-2 transducer, a sagittal section is obtained, making sure cortex is symmetrical on either pole.
2. Image optimized, region of interest optimized, central line aligned along long axis of kidney, patient made to stop breathing and sweep obtained. 3D volume data stored.
3. Reconstruction, volume measurements done offline.

Clinical impact of new volume imaging approach

• Stored volume data is useful for comparison of renal volume when patients came for follow up in nephrology and transplant outpatient departments.
• Improved demonstration of anatomical details of lesions within pelvicalyceal system and renal masses in relation to renal vessels.
Case study
A 43 year-old female patient with a previous history of renal calculi attended for ultrasound examination of the kidneys. 2D ultrasound showed a normal left kidney. There was a suggestion of multiple calculi within the pelvis of right kidney (Image A). A single volume acquisition scan was performed on the right kidney. By placing the MPR crosshair over the renal pelvis, it was possible to interrogate the pelvis with calculi. (Image B)

The views obtained after reconstructions were significantly better than using 2D ultrasound and showed a staghorn calculus, and not multiple calculi, as was the impression provided by 2D ultrasound. (Image C)

The staghorn calculus was also confirmed on digital X-ray. (Image D)
6. Volume imaging of the kidney

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**Key reason to consider 2D plus volume imaging approach**
Demonstration of the extension of a tumor within the renal vein and vena cava is better provided by 3D imaging than by 2D imaging. Post-treatment capabilities in this case are based on MIP-like images, with plane and thickness adapted to the anatomy of the studied case.

**How we do the exam**
1. After the 2D evaluation, use the V6-2 MHz transducer.
2. Find the best acoustic window using a posterior and lateral approach to the right kidney, and scan the kidney and the tumor on a long axis.
3. Use harmonic imaging, optimize depth, gain and focus.
4. Select the adequate sector angle to cover the tumor and the venous extension (here 55 degrees), and try to anticipate the patient breathing to minimize motion artifact.
5. Use the thick slice mode (24 mm) in the QLAB post-treatment.

**Clinical impact of new volume imaging approach**
Precise evaluation of a renal tumor and demonstration of extension into the draining venous system obtained with 3D imaging at the first diagnostic step, before CT or MRI examinations.

**Case study**
A two-year-old boy, presenting with a right abdominal mass. Ultrasound reveals a large mass (diameter = 10 cm) developed from the right kidney, suggestive of a nephroblastoma. A neoplastic extension to the renal vein and the inferior vena cava was seen on 2D sweeps. However, 3D imaging much more clearly demonstrated the shape of the venous extension and its upper limit, which remains below the diaphragmatic level, as confirmed on the subsequent CT scan.
Key reasons to consider 2D plus volume imaging approach

Despite the improvement of CT and MRI, sonography is still considered a first-line imaging method for evaluation of the liver. It is also contributive for the follow-up of chronic liver diseases (post-viral hepatitis, cirrhosis), for the detection of signs of portal hypertension, assessment of portal vein patency, and for the detection of possible hepatocarcinoma. Sonography also plays a role for the follow-up of liver transplantation and after transjugular intrahepatic portosystemic stent (TIPSS) procedures.

Based on at least one year of routine use of a volumetric transducer, 2D combined with volume imaging has contributed to optimizing our sonographic findings.

How we do the exam

1. Perform the liver investigation as usual, initially without volumetric acquisition, with the C5-1 or C5-2 transducer.

2. When a lesion or an anatomical variant appears during the sweeps, do at least two perpendicular volume acquisitions centered on the considered lesion with the V6-2 transducer, in the supine and left lateral decubitus positions.

3. Check the touchscreen of the iU22 system to be sure that all the area to investigate is included in the volume set.

4. Send these volumetric sets to the PC workstation equipped with QLAB software. These volume sets can be analyzed during the reporting time, when the patient has already left the practice room.

Clinical impact of new volume imaging approach

• The main contribution of adding volume acquisitions during liver scanning is better confidence for the location of a liver mass combined with lesser time duration of the examination.

• Volumetric acquisitions are then helpful for a better localization of lesions according to the liver segmentation.

• Degree of extension of a mass in the respective segments of the liver is also better evaluated. This contributes to a more precise visualization of vessels close to the lesions, and is then useful for the selection of specific treatments for malignant tumors (guided procedures or by surgery).

• Determination of a liver invasion by a neighboring mass, from the kidney for instance, is also achievable.

• An additional benefit is a better understanding of anatomic variants (both of the liver or its vascular network), allowing reduced misinterpretations and unnecessary additional exams such as CT or MRI.
7. Volume imaging of the liver
continued

Case study 1
This patient has a hepatocarcinoma. Surgery is planned for
treatment of this hepatocarcinoma. To aid the surgical
approach, ultrasound is required to identify the vessels
coming close to the lesion.

Images A and B. The lesion (arrowheads) is visible on B mode with a good correlation with MRI.

Images C and D. Volume acquisition is done for an optimal view of the vascularisation around this lesion, showing the vessels close to the liver lesion. The vessels (arrowheads) are near and within the liver lesion.

Image E. Correlation between pathology and
reformatted sonographic views (the vessels near
the lesion are pointed with arrowheads).
Case study 2

This patient is followed with an ultrasound after endovascular treatment of a hepatocarcinoma (chemoembolisation) in order to plan a liver transplantation. With conventional ultrasound, the extent of the site of treatment was difficult to assess, as well as the visualization of the portal vein near this site. Volume sonography was contributive for a better understanding of the situation.

Image A. iSlice screen of one volume set, centered on the site of the lesion.

Image B. By rotation of the images on the fourth view (the 3D view), we can better see the site of the lesion (white arrowheads), the thrombosed portal vein (yellow arrow) and its connection to the site of the lesion.

Image C. MRI correlation (examination within the same delay of the ultrasound).
Case study 3
Sonogram requested for the diagnosis of a liver mass detected during a routine examination. The volume approach was useful, showing the feeding vessel, which gave more confidence for the final diagnosis of focal nodular hyperplasia (FNH).

Image A. Volume set acquisition centered on the mass.
Image B. A reconstructed view based on volume set showing the vascular pedicle of the lesion.
Images C and D. CT and MRI correlations of the FNH.
Case study 4

This 55-year-old man is admitted for surgical resection of a huge renal carcinoma. Based on CT and conventional ultrasound, liver invasion by the renal tumor is strongly suspected. Volume ultrasound is required for an answer to this point. Volume acquisitions, by using iSlice, helped the demonstration of an absence of liver invasion by the renal tumor. We concluded an extrinsic compression of the liver parenchyma by the renal mass (surgically confirmed).

Images A and B. Axial and frontal CT reconstructions showing the renal mass and suspected invasion to the liver.

Image C. Conventional sonogram showing the renal mass and absence of separation of the renal mass from the liver.

Image D. Volume set acquisition centered on the upper part of the renal mass. With volume imaging, we concluded the absence of liver invasion on iSlice set of images.

Image E. On this coronal reconstructed view (arrow) the absence of liver invasion was confirmed during surgery (*renal mass).
7. Volume imaging of the liver
continued

Case study 5
A volume approach done in this case of follow-up of chronic hepatitis was contributive to the better understanding of the portal vein anatomy and the detection of an uncommon variant. During conventional sonogram, we note the absence of the left portal vein in its normal location, which could be related to agenesis, old thrombosis, or an anatomical variant. Based on the publication of Atri et al. the portal anatomy was better depicted.

Image A. Drawing of the common portal veins variants.

Image B. Volume set at the level of segment 1 and the portal bifurcation.

Image C. iSlice view of a volume set at the level of segment 1 and the portal bifurcation. We note the absence of the left portal vein at its normal location (arrow). This left trunk is upper located, within the liver parenchyma (arrowheads).

Images D and E. Frontal reconstruction on B mode showing the absence of the normal left portal vein (arrow) and the variant of its location (arrowhead), with schematic correlation.

**Case study 6**

This sonogram was done during the follow-up of cirrhosis. Volume acquisition gave us the opportunity for a better illustration of recanalized paraumbilical veins, difficult to show on conventional images and not visible on previous examinations.

Image A. iSlice screen showing one paraumbilical vein, only partially (arrowhead).

Image B. Drawing of common recanalized paraumbilical veins visible with ultrasound.

Image C. Volumetric reconstruction showing two paraumbilical veins coming from the « Rex » recessus.

* Adapted from Lafortune et al, AJR 1985, 144:549-553, The recanalized umbilical vein in portal hypertension: a myth.
Key reasons to consider 2D plus volume imaging approach

The liver is the largest organ in the body and it varies considerably in size and shape among individuals. The liver is located high in the abdominal cavity and deep to the rib cage. Several factors serve as challenges to the acquisition of good hepatic volumes including sensitivity to movement artifact from both respiration and from cardiac activity. Furthermore, common liver pathologies, such as cirrhosis and steatosis, may disrupt the normal liver parenchyma and size such that adequate access and penetration may be problematic.

Despite the potential obstacles to volumetric acquisition of liver data, techniques for performance of hepatic volumetric acquisitions may provide good data showing liver parenchyma, vasculature, and pathology.

How we do the exam

1. As with all volumetric scans, we follow a defined protocol which starts with a prescan. The prescan should determine the optimal placement of the transducer, the optimal phase of respiration for breathhold, the optimal focal zone and placement, and the optimal patient position: supine or left lateral decubitus.

2. The optimal plane for acquisition is generally in the long axis of the right and left portal veins as they arise from the main portal vein at the porta hepatis. This plane is easily achieved in most patients with a subcostal oblique transducer placement with angulation towards the right shoulder.

3. Acquisition is performed with suspended respiration, usually at full inspiration. This will generally show the hepatic venous confluence at one extreme of the volume and the structures of the hepatoduodenal ligament at the other extreme, as the acquisition essentially encompasses the entire organ in a single sweep.

In summary, the prescan determines:

- Choice of transducer frequency—generally, standard for abdomen
- Choice of transducer design—curved
- Choice of optimal plane for acquisition—subcostal oblique through plane of the portal venous confluence at the porta hepatis
- Choice of optimal acquisition technique—generally, mechanical
- Choice of optimal phase of respiration—generally, suspend in full inspiration

Difficult acoustic windows, small cirrhotic livers, very large liver masses, fatty liver, and obesity all compromise the success of this technique.

Clinical impact of new volume imaging approach

In our study at the University of Calgary consisting of 200 consecutive patients, successful liver volumes were obtained on the majority of patients, with documented failures related to end-stage cirrhosis and obesity. In our experience, liver status (normal, cirrhotic, or fatty) is accurately assessed on a single volume in the majority of patients. Focal liver masses and their relationship to the vital vascular structures are also well demonstrated with a three-dimensional technique.

- Appreciation of the normalcy or abnormalcy of the liver is optimally determined on a volumetric acquisition. Liver size, contour, lobar distribution, and echotexture can all be shown in a single sweep (Image A).
- In patients with focal disease, a good acquisition shows the number, distribution, and morphology of lesions, often reducing the necessity for hands-on review of the pathology by the physician.
- In the patient with potential surgical disease, the relationship of pathology with the vital vascular structures in the liver can be optimally shown on a volumetric multi-planar reconstruction (MPR) series of images (Image B).
Case study 1

A normal liver in an asymptomatic young woman is shown in a nine-on-one stacked format in the acquisition A plane. The center image is the starting point for the subcostal oblique acquisition, and it shows the long axis of the right and left portal veins at their origin from the main portal vein. The image (top left) shows the structures of the portal triad within the hepatoduodenal ligament at the caudal border of the liver. The bottom three images all show the hepatic venous confluence at the inferior vena cava and the cephalad border of the liver. Therefore, a single such acquisition shows virtually the entire liver and its vascular structures.

Image A. Nine on one stacked format in the axial plane of a normal liver.

Case study 2

A 58-year-old man with known colorectal cancer is scanned to determine resectability of a suspect liver metastasis. A multiplanar reconstruction shows the liver mass within a large fatty liver in the acquisition A plane (left) in the long axis B plane (top right) and in the coronal C plane (bottom right). The close proximity of the segment 8 mass to the middle hepatic vein is shown with clarity on the A and C plane images. The volume data provides information about the size and texture of the background liver. It is both large and fatty and, in addition, it shows the solitary and large tumor mass with its relationship to vital vascular structures.

Image B. A multiplanar reconstruction shows a large right lobe liver metastasis in all three planes.
9. Volume imaging of the bowel

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**Key reasons to consider 2D plus volume imaging approach**

The advent of high resolution machines and high frequency probes has made ultrasound imaging of the bowel a reality. While there are still limitations in evaluating intrinsic lesions in the bowel lumen with conventional ultrasound, volumetric imaging has been useful in evaluating intrinsic lesions within the bowel, as well as bowel wall pathologies.

Volumetric imaging has potential to visualize the lumen of bowel just as virtual scopy on CT scan. The rapid collection of data and the ability to analyze data at a later stage are the greatest advantages of volumetric imaging.

**How we do the exam**

The volume ultrasound of bowel is performed with a V6-2 probe and an xMATRIX probe. Unless there is clinical contraindication, like an acute abdomen, hydration of patient helps in evaluation of bowel.

**Examination with V6-2 transducer**

1. Area of interest was identified with conventional ultrasound using linear 12-5 or linear 9-3 probes.
2. Area of interest matched with region of interest and volume sweeps obtained.
3. Once satisfactory area covered, volume data stored with volume 3D store.
4. Analysis done with QLAB after patient left the clinic.
5. Threshold used to optimize region of interest.

**Examination with xMATRIX transducer**

1. Area of interest was identified using linear L12-5 or linear L9-3 probes.
2. xMatrix probe was then used in the area of interest in its Live 3D mode. This setting gives live 3D images of the area of interest.
3. Images were optimized for gray scale and chrome was used.
4. Images were optimized to visualize inside of the bowel lumen.
5. Loops were stored in live capture.

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Image A. Poor definition of bowel and mesentery.

Image B. Volume data with volume ultrasound.

Image C. Analysis with QLAB showing bowel loop with mesenteric thickening clearly.

Image D. Intrinsic lumen of bowel on xMATRIX probe-sonoscopy.
10. Volume imaging of the bowel in patients with Crohn’s disease

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**Key reasons to consider 2D plus volume imaging approach**

Crohn’s disease (CD) is the most common form of inflammatory bowel disease (IBD). The peak age of onset is between adolescence and early adult life. With each exacerbation of symptoms, the patient is subject to diagnostic imaging procedures to show the status of the disease.

CD is frequently evaluated with cross sectional imaging techniques, including sonography. The imaging objective is to efficiently show the extent and activity of CD and to detect and characterize any complication. The extent and activity are determined by assessing the classic features of CD, which include gut wall thickening, inflammatory fat, perienteric lymphadenopathy, and hyperemia. The complications include stricture, mechanical bowel obstruction, perforation, fistulization, and inflammatory masses, however they are more difficult to predict and assess.

A CT scan is the most frequent choice to evaluate CD. Considering the young population most often affected, and also the chronic nature of CD, this choice of radiation procedure is untenable. Sonography is shown in multiple publications to be sensitive to the detection of gut wall thickening in CD, and it is also able to identify complications. However, the single frame image display most often used in sonography does not allow the referring clinician to adequately appreciate the pathology that might be shown on a sonogram, especially in patients with significant complications. Furthermore the magnitude of change may be substantial, consequently, neither the relationships nor the complexity can be appreciated without a hands-on evaluation.

A volume acquisition allows for a real-time review of the data in all three planes as well as allowing for multi-planar reconstruction (MPR) of the data to show intricate associations and relationships otherwise impossible with ultrasound. This is a premier application for volume imaging and, in our practice, it surpasses all others. Perhaps in no other area of sonography does volumetric acquisition of data have such a profound impact as in the evaluation of a patient with CD.

**How we do the exam**

1. A prescan is required to identify the abnormal bowel loops by visualization of the classic features defining CD.
2. Once identified, the choice of the correct transducer frequency is required, often a high frequency linear or curved probe.
3. The optimal plane for acquisition is determined and the choice of method of acquisition is chosen. The options include a freehand acquisition, which has the advantage of allowing a longer length of acquisition, or a mechanical acquisition, which makes a smaller volume and suffers from loss of resolution in the perpendicular planes.

The optimal respiratory phase for volume imaging of the bowel is often less critical than for many of the solid organs. However, the bowel is often mobile, and suspended respiration may improve the data acquisition.
In summary, the prescan allows for:
• Choice of transducer frequency—as high as possible
• Choice of transducer design—curved or linear
• Choice of optimal plane for acquisition—often cross section
• Choice of optimal acquisition technique—preference is freehand
• Choice of optimal phase of respiration—generally, suspend in expiration

The volume acquisition is performed with the focal zone set at the midpoint of the bowel lumen, and the field of view set to include several centimeters of soft tissue both superficial and deep to the bowel.

The volume data should then be reviewed for completeness and accuracy. If necessary, additional volumes or AVI acquisitions should be performed to show relevant changes in the bowel activity, exaggerated peristalsis, dysfunctional peristalsis, to-and-fro peristalsis, and blood flow to the abnormal bowel and abnormal soft tissues.

Once pathology is identified, an acquisition volume is often performed in both the long axis and in the cross sectional plane to encompass the entire length of abnormal bowel, with inclusion of the perienteric soft tissues.

**Clinical impact of new volume imaging approach**
• With utilization of freehand acquisition, volumetric imaging of the bowel is of considerable value, surpassing every other application we have investigated (Image A).
• The presence, extent, and degree of activity of the inflammatory process in the bowel are established (Image B).
• The presence of any complication is shown in relationship to the bowel and surrounding soft tissue.
• Ultrasound with volumetric imaging provides information equivalent to a CT scan without the requirement for ionizing radiation.
• It is available, safe, and easily performed while showing the classic features of Crohn’s disease as well as its frequent and significant complications.
Case study 1
A 44-year-old woman with known Crohn’s disease for seven years. Surveillance volume scan acquired in the axial A plane (left) shows thick gut with wall layer preservation. The long axis B plane (right top) shows a long and continuous length of abnormal bowel, providing information about disease extent. The coronal C plane (bottom right) shows both the long segment of involved bowel, and the adjacent echogenic inflamed fat exceptionally well. There is no evidence of complication.

Case study 2
Highly complicated Crohn’s disease with microperforation and incomplete mechanical bowel obstruction in a 54-year-old man with known inflammatory bowel disease and recent acute flare of symptoms.

Emergency ultrasound of the right lower quadrant with multiplanar reconstruction shows the acquisition A plane is in the long axis of the abnormal gut (left) and the axial B image (right bottom) with the coronal C view (top right).

The long and continuous length of severely thickened gut shows luminal apposition distally, on the left of the long axis image, with a dilated, air-filled segment proximal, on the right of the long axis view. Intensely inflamed echogenic fat, and a serrated border to the deep edge of the gut, suggests perforation with phlegmon, especially on the long axis and short axis views.
11. Volume imaging of the intestine

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Key reasons to consider 2D plus volume imaging approach
Despite the improvement of CT and MRI, sonography is still considered as useful in patients having, or suspected of having, acute intestinal disorders, acute appendicitis, diverticulitis, and inflammatory bowel diseases (IBD). Since at least one year ago, we routinely use volumetric imaging, combined with conventional approach, in patients with bowel inflammation. Detection of gut wall thickening, mural vascularization, abscesses, and fistula are better estimated with this combined approach.

How we do the exam
1. Perform the gut investigation as usual, initially without volume acquisition, with the C5-1, C5-2 or a linear transducer.
2. When a gut wall change or increased echogenicity of the peridigestive fatty tissue appears during the sweeps, do at least two perpendicular volume acquisitions centered on the considered target area with the V6-2 transducer.
3. Check the touchscreen of the iU22 to be sure that all the area to investigate is included in the volume set.
4. Analyze these volume sets with QLAB software during the reporting time, when the patient has already left the practice room.

Clinical impact of new volume imaging approach
• The most relevant contribution of adding volume imaging for scanning in intestinal diseases is the availability of enough images, allowing an optimal comparison and follow-up of patients with complicated forms of IBD (due to abscesses and fistula), in combination with a reduced duration of the examination.
• Volume acquisitions are helpful for a better localization of perigut changes, particularly the fistular tracts and abscesses closely located to bowel segments.
• The availability of volume sets in a storage system allows a better comparison between sequential examinations in order to assess the effect of the therapy.
Case study 1
A middle age man is admitted for acute left iliac fossa pain. A conventional sonogram is required for the diagnosis work-up. This case is helpful for the demonstration of the diagnostic findings for acute left side diverticulitis and the correlation with CT images.

Image A. Ultrasound is showing colic wall thickening, suspicion of inflamed diverticulum and increased echogenicity of the pericolic fat tissue. Volume acquisitions were done for an optimal view of this suspected acute left side diverticulitis.

Image B. Acquisition of two volume sets, one in the axis of the inflamed colon and one perpendicular to its long axis.

Image C. On the iSlice view, the length of the colic wall thickening is well seen (arrows) as well as the inflamed diverticulum (arrowheads).

Image D. CT slice at the level of the inflamed diverticulum.
Case study 2
This case is illustrative of the contribution of volume ultrasound for an easier vision of complications in inflammatory bowel disease. This ultrasound was requested for a young woman with a known Crohn’s disease and a high degree of clinical suspicion for recurrent complication (abscess and/or fistula).

Image A. Initial screen view at the time of acquisition of the volume set.

Image B. iSlice screen subdivision at the level of the higher degree of intestinal inflammation.

Image C. Reconstructed image obtained after rotating the volume.

Image D. Closer view of a reconstruction showing a gas containing mesenteric abscess (arrow) connected to the distal ileum (curved arrow) with a fistula (arrowhead).
Case study 3

A young patient with suspicion of reactivation of Crohn’s disease. The contribution of volume approach was for a better depiction of the relations between the different segments of the affected ileum, the caecum and the appendix. (The involvement of the appendix was depicted by using iSlice process and reformatted images.)

Image A. iSlice screen view at the time of acquisition of the volume set showing the different segments of the inflamed ileum and the fistula.

Image B. Reconstructed image obtained after rotating the volume showing the more inflamed ileum and an intestinal segment coming from the caecum.

Image C. Additional reconstructed image at the same place after rotating the volume is helpful for the identification of this intestinal segment coming from the caecum: this is the appendix.

Image D. Correlation between a MPR view of the caecum, the appendix and its connection to the distal ileum.
Case study 4
A young woman referred for an ultrasound for suspicion of reactivation of known Crohn’s disease. Using the volume approach, fistula and abscesses were easier to see.

Images A and B. Conventional ultrasound is showing ileal wall thickening (arrows) and suspicion of fistula (arrowheads) into the inflamed mesenteric folds.

Image C. Global view of the volume set centered just in front of the site of the more pronounced peridigestive changes.

Image D. Ileal wall thickening (arrowheads) with extradigestive, mesenteric hypoechoic process (fistula, thin arrow) connected to another segment of the bowel (large arrow).
Key reasons to consider 2D plus volume imaging approach

The pancreas is a narrow, thin organ with one long and two short dimensions. Its shape is ideal for the best volumetric acquisitions. The pancreas has constant vascular landmarks which allow for reproducible and consistent results for the volume acquisition.

The pathologies of the pancreas of interest to cross sectional imagers include only two groups of diseases, tumors and inflammatory processes. A tumor is manifest as a mass in the pancreas. Demonstration of a tumor mass in both the long axis and the cross sectional plane is critical to successful interpretation of the nature of the mass and its relation to the vital vascular structures. Inflammatory processes involving the pancreas cause diffuse pancreatic abnormality and abnormality of the surrounding soft tissues. Their study requires comprehensive evaluation of multiple pancreatic and peripancreatic acquisition slices.

With conventional single-frame image acquisition, images in perpendicular planes are acquired. However, with a real-time multiplanar technique, a mass, and its relationships to vital vascular structures, may possibly be viewed with only a single acquisition.

In cystic pancreatic neoplasms, the relationship of the cystic masses to the pancreatic duct is also critical. The volumetric technique may, in a good examination, show the entire duct and its relationship to the cystic mass.

How we do the exam

1. A prescan is performed to identify the pancreas and determine how it is best shown on the sonogram. The prescan assesses whether the patient should lie quietly supine or whether a variety of breathing maneuvers should be employed to optimize the assessment.

While searching for the pancreas, we have found that imaging in the sagittal plane, centered on the confluence of the superior mesenteric vein and the splenic vein behind the pancreatic neck, is optimal. From this vantage, the transducer can be angled to the right to show the pancreatic head ventral to the inferior vena cava and then to the left to show the pancreatic tail ventral to the splenic vein and artery as it runs to the region of the hilus of the spleen.

2. Once this pancreatic anatomy is determined, rotation of the transducer to the axial plane will require only slight correction to show the pancreas in its long axis in its entirety, generally by angling the transducer slightly cephalad on the left and slightly caudad on the right.

3. Once attained, the ideal plane for the acquisition should be in the long axis of the gland with the center point set on the spleen vein as it runs from the portal venous confluence to the splenic hilum. The cephalad limit should include the celiac axis and the caudal limits should include the most inferior aspect of the pancreatic head and the duodenal sweep.

In summary, the prescan determines:

- Choice of transducer frequency—generally, standard for abdomen
- Choice of transducer design—curved
- Choice of optimal plane for acquisition—axial, in the long axis of the pancreas as determined by the course of the splenic vein
- Choice of optimal acquisition technique—generally, mechanical
- Choice of optimal phase of respiration—highly variable, ranging from full inspiration, full expiration, quiet breathing and use of breathing maneuvers
Clinical impact of new volume imaging approach

Pancreatic assessment with volumetric acquisition is susceptible to the same challenges that influence the success of routine sonography of this organ. Therefore, even with meticulous technique and maneuvers, there will be a small, but definite, failure rate. Obesity is not the only factor which hampers success. Rather, the relationship and the appearance of the overlying transverse colon seemingly exerts the largest influence on success. Nonetheless, many patients will have excellent volumetric results showing the entire pancreas in a single acquisition.

- A successful acquisition shows the pancreas tissue, the vital regional vascular structures, and the peripancreatic soft tissues.
- Demonstration of a pancreatic mass will show its location, effect on the pancreatic duct and its relationship to vessels.
- A good study is of enormous contribution to diagnosis of pancreatic pathology and, in the case of neoplastic disease, to determine operability.
- Most often, a single acquisition may show the entire gland in a patient with a good acoustic window (Image A).

A mass in the region of the pancreas can be confirmed to be pancreatic or not. The precise location of the mass, as well as its relationship to the vital vascular structures in and around the pancreas, is generally shown. Additional intrapancreatic pathology and peripancreatic pathology will also frequently be included in a good acquisition. Therefore, as with all successful 3D acquisitions, the pancreas may be superbly shown in its entirety.

The pancreas is one of many organs most often evaluated with CT scan. Multiplanar imaging and assessment of AVI files allow for valuable presentation of data with demonstration of relationships and multiple features in a single file. The presentation of data will only improve with removal of the mechanical technique. The benefit afforded by single frame imaging of the pancreas is shared by volumetric acquisition in that pancreatic tumors show striking contrast differential from normal pancreatic tissue. When used in a volume acquisition, this striking ability to show pancreatic tumors allows for improved determination of their resectability (Images B and C). In inflammatory conditions, the extent and amount of peripancreatic change is also optimally assessed with volumetric techniques.

In our own study at the University of Calgary of volumetric imaging in 200 consecutive patients, the pancreas was satisfactorily imaged with volumetric acquisition.
Case study 1
A normal pancreas is shown in a nine-on-one stacked format in the acquisition axial plane. The center image is the starting point for the acquisition, and shows the splenic vein and the portal venous confluence. A large portion of the pancreas parenchyma shows on this image. The pancreatic head images are shown (top left and top middle). The cephalad border of the pancreas, the celiac axis image, is shown (bottom middle). The three images on the right include the top, axial, and middle long axis, showing the celiac axis. The bottom right image shows the location of the stacked images as represented on the coronal plane.

Case study 2
Malignant IPMN in an 81-year-old man. Image B, (large) shows the acquisition axial plane with the portal venous confluence and an attenuated, but patent, splenic vein. The pancreatic duct is very dilated in the body ad tail. A complex cystic and solid mass replaces the pancreatic head. The image (top right) shows the cystic mass in the head in the long axis, and the image (bottom right) shows the dilated pancreatic duct coursing through the pancreatic head. Image C (center image, middle row) shows the splenic vein and the portal venous confluence (left image, middle row). A dilated pancreatic duct is shown in the body and tail. The head is replaced with a complex cystic and solid mass. The bottom images and the other two images in the middle row show the cystic dilated side branches of the pancreatic duct.

Image A. Normal pancreas in a nine on one stacked format in the axial plane.

Image B. Malignant IPMN shown with multiplanar reconstruction.

Image C. Malignant IPMN shown in a nine on one stacked format in the axial plane.
13. Volume imaging of breast tumors and normal findings

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**Key reasons to consider 2D plus volume imaging approach**
Better assessment of infiltration in the coronal plane, of the tumor local extension (satellite lesions to a main cancer tumor), and in the C-plane.

This approach offers a new possibility to examine and analyze, by images, the internal structure of the tumors and a better approach to the real size of the lesions.

**Clinical impact of new volume imaging approach**

**Clinical impact for radiologists**
• New and excellent images in the C-plane and better assessment of the behavior of the infiltration in the surroundings to the cancer tumor
• Better assessment of lesion size and extension
• Helps increase tumor diagnosis
• The possibility of seeing the internal structure and an increase in the diagnosis confidence for the benign lesions

**Clinical impact for surgeons**
• Better assessment of real lesion size
• Helps increase confidence in tumor diagnosis

**Clinical impact for oncologists (in big tumors or local advanced disease)**
• Better assessment of the tumor’s volume which is important to evaluate the response to neoadjuvant therapy
• Assessment of the internal structure (necrosis) which might help to evaluate the response to neoadjuvant therapy

**How we do the exam**

**Acquisition settings and workflow**
1. After localizing the lesion in 2D, proceed to do the volume images.
2. The best 3D image is a result of the best optimized 2D image. Parameters such as the following should be adjusted: gain, depth, focus, frequency, RES/SPD, compression and so on.
3. Tissue aberration correction (TAC) selection always ON.
4. Select maximum angle.
5. Do not use ROI.
6. Select RES option under the 3D menu.
7. Position the transducer to obtain the maximum length of the lesion.
8. The acquisition sweep should extend beyond the borders of the target anatomy to insure that everything is included.
9. No motion during the acquisition is desired.
10. Choose the corresponding orientation labels.
11. Save the 3D data set.

**Default data set settings**
• 3D vision B
• Volume chroma 3
• Volume Map 2
• Threshold 6%
• Transparency 15%
• Brightness 32%
• Lightning 30%
• Smoothing 0%
• Sono CT and XRes on
Case study

A 67-year-old female patient with a 19 mm BI-RADS 5 lesion at one o’clock in the left breast by mammography. Same finding with 2D ultrasound. The 3D volume image (review) shows a satellite lesion not detected with 2D ultrasound or mammography. This is a good example in which the review of the 3D images gives more information about the size and extension of the malignant process, improving the outcomes of the surgery. The pathology specimen showed a 25 mm invasive ductal carcinoma Elston-Ellis grade 2, SN (sentinel node) negative.
Key reason to consider 2D plus volume imaging approach

The main reason is the fact that the operator is able to obtain a continuous vision of all planes.

This approach is helpful in assessing uterine malformations and the relationship between lesions and adjacent organs, as well as the thickness of cleavage plans in order to plan a surgical strategy. It is also helpful in the detection of vessels, and the understanding of their relationship with lesions and malformations.

How we do the exam

1. When the scan is performed by an expert sonologist, the 3D acquisition is directed to obtain three planes in order to reach a differential diagnosis. In these cases, the 3D imaging is an integration of the conventional 2D scan and must be directed towards a specific diagnostic question.

2. When the 3D acquisition is performed by an operator who is quite inexperienced in vaginal ultrasound, volume imaging allows a post-processing evaluation performed later by an expert sonologist.

3. Volume imaging allows retrieving diagnostic information that could have been ignored by the inexperienced operator. This is even more important when the scan is performed by an obstetrician, a radiographer or a nurse.

The field of view of the volumetric scan could not contain the entire pelvis. Therefore, we suggest performing:

- A scan that includes the uterus and the right ovarius
- A scan that includes the uterus and the left ovarius
- A scan that includes the uterus and the bladder
- A scan that includes the uterus, the rectum and the Douglas space

Clinical impact of new volume imaging approach

The volume imaging seems to have its best expression in the detection, evaluation, and description of uterine malformations.

In addition, some further features should be considered, such as:

- The possibility of a second look in consensus with the physician who is in charge of the patient. This may allow the integration of the examination with other findings that might not have been considered during the scan.

- The possibility of a second look in consensus with the surgeon who is in charge of the patient. A conjoined evaluation may result in an improved assessment in terms of surgical planning (relationship of the lesion or malformation and its relationship with vessels).
**Case study 1**

A 24-year-old female with a history of infertility reported recent occurrence of metrorrhagia and repeated vaginal bleeding. A conventional 2D ultrasound scan showed a relevant thickening of the endometrium (*Image A*). The scan was performed in the ninth day of the menstrual cycle. Then sonohysterography and 3D imaging were performed. These scans showed multiple endometrial polyps that were lying along the whole circumference of the internal uterine cavity (*Image B*). In this case, 3D imaging was fundamental in the planning of hysteroscopic resection, demonstrating precisely the site, dimension, and features of each lesion.

**Image A.** Thickening of the endometrium (arrows).

**Case study 2**

A 34-year-old female with a history of infertility and recurrent abortions. Conventional trans-abdominal 2D scan demonstrates a duplication of the uterine body. Both bodies are clearly visible in the axial 3D scan with the bladder in between (*Image C*). In addition, 3D imaging was the only method to identify the double uterine cervix (*Image D*). The association with a vaginal septum detected at the gynecological examination allowed us to make a diagnosis of uterus didelphys.

**Image B.** Multiple polyps in the cavity, in three-plane reconstruction (arrows). Volume reconstruction shows an opened uterine cavity where polyps are clearly demonstrated (arrows).

**Image C.** U = uterine body, B = bladder.

**Image D.** Arrows indicate cervix duplication.
Key reason to consider 2D plus volume imaging approach
Capability to conduct a full volumetric examination, including 3D grayscale, 3D color Doppler mode, and 4D contrast-enhanced sonography. This type of examination allows the evaluation of small tumors in any plane, including those which could not be displayed by 2D modes.

How we do the exam
1. After the 2D evaluation, use the VL13-5 MHz transducer, as the lesion is superficial.
2. Based on a coronal view, cover the entire area with a 40 degree sector angle. Multidirectional reformation shows the appearance of the tumor, and its relationship with the kidney capsule and parenchyma.
3. For 3D color Doppler imaging, use low PRFs and decrease the gain to minimize motion artifacts and concentrate on main vessels. Superimposing Doppler signals in a volume nicely demonstrates vascularity.
4. For 4D contrast-enhanced ultrasound, inject 2.4 ml of Sonovue (Bracco, Italy), and obtain seven consecutive volumetric acquisitions with a sector angle of 25 degrees.
5. In QLAB, work within a thick slice to display anomalies and obtain images which can be compared with CT reformatted images.

Clinical impact of new volume imaging approach
Higher spatial resolution and better information on vascularity than provided by 2D ultrasound, CT, and MRI.
Case study

A small round shaped tubulo-papillar carcinoma was discovered in upper pole of the renal transplant on MRI follow-up in a 30-year-old man. Subsequent evaluation was made on ultrasound and CT.

Image A. T2-weighted MRI image demonstrates a 1.2 cm tumor in the upper pole of the allograft (arrow).

Image B. Multiplanar display of the tumor and its relationship with adjacent capsule and parenchyma, especially in the sagittal plane (arrows).

Image C. Thick slice obtained from a 3D color Doppler volumetric acquisition shows feeding vessels and spare intratumoral vascularity.

Image D. 3D contrast-enhanced ultrasound obtained during the arterial phase displays the feeding artery and slow flow enhancement within the tumor (arrow).

Image E. Based on a 3D acquisition, calculation of infarcted and vascularized parenchymal volumes can be easily performed. Values are respectively 109 ml and 81 ml.
16. Volume imaging of a renal transplant
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**Key reason to consider 2D plus volume imaging approach**
Difficulties in evaluation of the extension of a cortical necrosis on 2D contrast-enhanced double screen acquisition.

**How we do the exam**
1. After the 2D evaluation, use the V6-2 MHz transducer.
2. Based on a long axis view, select a large sector angle to cover the entire renal allograft area (45 degrees).
3. For repeated 3D contrast-enhanced ultrasound, inject 2.4 ml of Sonovue (Bracco, Italy), and obtain four consecutive volumetric acquisitions in the early phases.
4. In QLAB, use a thick slice (approximately 8 mm) to display vascularity anomalies and obtain images which can be compared with CT axial images.

**Clinical impact of new volume imaging approach**
- Better evaluation of the extension of cortical necrosis on 3D acquisition than on 2D for contrast-enhanced ultrasound.
- This evaluation allows avoidance of allograft biopsy and the proposal of a follow-up based on ultrasound.

**Case study**
A 48-year-old woman with a sudden loss in renal function on the tenth day after renal transplantation with a cadaver allograft. Grayscale and color Doppler acquisition were considered as normal, with an RI value of 0.72. Contrast-enhanced sonography was performed to look for parenchymal vascularization defects, and a cortical necrosis was found.

Images A and B. Grayscale and Doppler images show a deep, but normal allograft, with patent segmental and interlobar vessels.

Image C. 3D contrast-enhanced ultrasound nicely demonstrates the absence of perfusion in the superficial cortex (arrows), and accurately shows patent arcuate vessels (arrowhead).

Image D. CT correlation at the arterial phase confirms the superficial necrosis (arrows) but shows less anatomic detail than thick-slice volume contrast-enhanced ultrasound.
Key reason to consider 2D plus volume imaging approach
Difficulties in evaluation of the extension of a varicocele upon 2D acquisition.

How we do the exam
1. After the 2D evaluation, use the VL13-5 MHz transducer as the varicocele and testicle are superficial.
2. Based on a sagittal view, cover the entire area with a 40 degree sector angle.
3. Multidirectional reformation shows the appearance of the varicocele in a spectacular way, and its relationship with the upper pole of the testicle.

Clinical impact of new volume imaging approach
Better display of the persistence of the varicocele despite an embolization of the internal spermatic vein.

Case study
A 15-year-old boy being evaluated for recurrent left varicocele after embolization of the internal spermatic vein. Evaluation of the varicocele.

Images A and B. 2D ultrasound confirms the persistence of the varicocele which surrounds the upper pole of the left testicle.

Images C. 3D volumetric acquisition nicely demonstrates the varicose venous network covering the testicle.
18. Volume imaging of nutcracker syndrome

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**Key reason to consider a 2D plus volume imaging approach**
Insufficient evaluation of the entrapment of the renal vein by 2D imaging.

**Clinical impact of new volume imaging approach**
Better anatomic description of the venous entrapment (diameter, length).

**How we do the exam**
1. After the 2D evaluation, use the V6-2 MHz transducer.
2. Based on a transverse approach, select a sector angle of 30 degrees, which allows the coverage of the epigastric area.
3. For 3D grayscale imaging, use harmonic imaging, optimize depth, gain and focus, and make the acquisition during a breath hold.
4. In QLAB, work within a thick slice to display anomalies and obtain images.

**Case study**
A 15-year-old boy being evaluated for recurrent left varicocele after surgical ligature. Evaluation of the left renal vein for a potential compression between the aorta and superior mesenteric artery (suspicion of nutcracker syndrome).

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*Image A.* Left renal phlebography shows moderate renal varices (arrows) and compression of the main renal vein at the level of the aorta (arrow).

*Image B.* Transverse color Doppler view shows a dilated renal vein and high flow at the level of the segment between the aorta and the superior mesenteric artery (arrow).

*Image C.* 2D grayscale imaging hardly shows the entrapment of the renal vein between the aorta and SMA.

*Image D.* 3D grayscale imaging nicely shows the entrapment of the renal vein between the aorta and SMA, with a 0.5 mm diameter and 5 mm length.
Key reasons to consider 2D plus volume imaging approach
The volumetric complement is very useful to display the size and the implementation of the recurrent polyp developed at the bladder neck, and considered potential risk for outlet obstruction.

How we do the exam
1. After the 2D evaluation, use the V6-2 MHz transducer.
2. Based on a transverse axis, select the adequate sector angle to cover the bladder neck area (40 degrees).
3. Use harmonic imaging, optimize depth, gain and focus.
4. In the post-treatment phase, use QLAB and work with the thick slice mode (24 mm) with the slice centered on the bladder neck.

Clinical impact of new volume imaging approach
Allows a cystoscopy-like display of the lesion, and makes non-invasive follow-up easy.

Case study
A two-year-old girl, having a Beckwith-Wiedemann disease diagnosed since birth, presenting with a bladder polyp, initially resected by cystoscopy. Follow-up by ultrasound shows recurrence of the polyp three months later.

Image A. Transverse 2D view shows the recurrent small polyp close to the bladder neck (diameter 7 mm). The precise shape and relationship with the bladder neck cannot be easily assessed.

Image B. 3D imaging allows for cystoscopy-like images. Demonstration of the polyp basis (arrow) and of development just above the bladder neck (arrowhead) can be much better done on 3D data than on 2D images.
20. Volume imaging of the bladder

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Key reason to consider 2D plus volume imaging approach
Better demonstration to the referring surgeon of the anatomical findings.

How we do the exam
1. After the 2D evaluation, use the V6-2 MHz transducer.
2. Based on a transverse axis, select the adequate sector angle to cover the trigone area (40 degrees).
3. Select harmonic imaging, optimize depth, gain and focus.
4. In QLAB, use the multiplanar reconstruction and determine which plane would be the most useful to display abnormalities (here, the coronal view).
5. Work within a thick slice to produce the cystoscopic view.

Clinical impact of new volume imaging approach
• Easy confirmation of the widely opened ureteral orifice.
• The inadequate location of the per-endoscopic injection of material, to prevent from reflux into the upper urinary tract.

Case study
A 10-year-old boy, presenting with grade 4 right vesico-renal reflux in a megaureter, causing recurrent urinary tract infection (UTI). The urologist injected, by endoscopic approach, a gel of dextranomer microspheres around the ureter orifice to prevent urine from flowing back up. An ultrasound is performed because of a new episode of UTI.

![Image A](Image A. 2D ultrasound shows an opened ureteral orifice within the bladder (arrowhead) and deflux amount distant from the orifice (arrow).)

![Image B](Image B. 3D acquisition allows the reconstruction of a coronal view which could not be obtained directly, confirming the widely opened lower ureter (arrowhead).)

![Image C](Image C. A 3D cystoscopy-like view better demonstrates the orifice remaining opened, and the distant, inefficacious, gel ball.)

![Image D](Image D. Radiological voiding cystography confirms the massive reflux in the upper tract through the opened ureteral orifice.)
Key reasons to consider 2D plus volume imaging approach
Better display of vascular traumatic lesions and calculation of the volume of parenchyma remaining perfused.

Clinical impact of new volume imaging approach
Better follow-up of the patient, based on ultrasound, instead of repeated CT scans.

How we do the exam
1. After the 2D evaluation, use the V6-2 MHz transducer.
2. Based on a long axis view, select a large sector angle to cover the entire renal area (60 degrees).
3. For 3D grayscale imaging, use harmonic imaging, optimize depth, gain and focus.
4. For 3D color Doppler imaging, use rather high PRFs and decrease the gain to minimize motion artifacts and concentrate on main vessels.

For 4D contrast-enhanced ultrasound
1. Inject 2 ml of Sonovue (Bracco, Italy), and obtain five consecutive volumetric acquisitions.
2. In QLAB, work within a thick slice view to display anomalies and obtain images which can be compared with CT coronal reformatted images.
3. Calculate the volume of the vascularized portion of the kidney from the entire volume.
Case study

A 14-year-old girl, who fell from a bridge. Pain in the left lumbar fossa, hematuria. In this context, a CT scan was performed first, showing a fracture of the spleen, a traumatic dissection of the main left renal artery and a patent inferior polar artery feeding the left kidney lower pole. 3D ultrasound and 3D contrast-enhanced ultrasound was performed a few days after to follow the evolution of lesions, confirming the absence of vascularity within the middle and upper pole, and a patent inferior artery with normally vascularized lower pole.
Key reasons to consider 2D plus volume imaging approach

The shoulder is one of the most common fields of application of ultrasound in the musculoskeletal system. In the last years, many changes have occurred that have had a positive impact on the practice of shoulder ultrasound, including improved visualization of shoulder structures, refinement of the criteria for diagnosing rotator cuff tears, and standardization of the examination technique.

Conventional 2D ultrasound requires systematic scanning of each of the four rotator cuff tendons (that is, subscapularis, supraspinatus, infraspinatus, and teres minor) and the long head of the biceps tendon according to long-axis and short-axis planes. Some inter-observer variability is related to this process.

In specific working settings (such as, ultrasound exams performed by medical sonographers and remote teleradiology context), volume ultrasound can contribute to overcoming operator dependence and to improving the accuracy of identification of rotator cuff tears. In addition, it can play a role in better delineating of normal and pathologic findings in patients with rotator cuff disease.

Volume ultrasound enables capture of the whole rotator cuff in three datasets: anterior (for the subscapularis), cranial (for the supraspinatus), and posterior (for the infraspinatus and teres minor). The posterior dataset can give simultaneous depiction of the posterior recess of the glenohumeral joint. Superficial to the rotator cuff, the subacromial-subdeltoid bursa can be evaluated in each sweep by considering its anterior, superior and posterior aspects respectively.

The biceps tendon is excluded from 3D volume analysis due to both its excessive length relative to the file of view of the acquisition volume and curved course at the intraarticular level, when the tendon reflects over the convexity of the humeral head, leading to variable degrees of anisotropy during the automated sweep. Thus, after 3D volume acquisition, the exam needs further 2D ultrasound complement to assess the biceps tendon. AC joint evaluation can also be accomplished using conventional 2D technique at the end of the study.

The three datasets are reviewed in several planes, including the C-plane, which is parallel to the tendon width and cannot be obtained with conventional 2D ultrasound.
How we do the exam
1. Using the VL13-5 transducer, locate the rotator cuff tendons as for conventional 2D scanning.
2. Optimize the gray-scale settings using the highest resolution possible.
3. The volume ultrasound acquisition consists of three sweeps over the rotator cuff tendons obtained with the patient seated on a revolving stool and the examiner located in front. The shoulder should be positioned as follows:
   a. Anterior sweep—The patient’s arm is externally rotated to move the subscapularis tendon anteriorly. (This maneuver helps to reposition it from underneath the coracoid.) In this position, align the A-plane (the basic 2D scan plane) with the midline of the long axis of the subscapularis.
   b. Cranial sweep—The patient’s arm is extended posteriorly and the palmar side of the hand is placed on the superior aspect of the iliac wing with the elbow flexed, directed posteriorly and towards midline. (This maneuver helps to reposition the supraspinatus tendon from under the acromion.) In this position, align the A-plane with the midline of the long axis of the supraspinatus.
   c. Posterior sweep—The patient’s hand is placed on the ipsilateral thigh, palm up. In this position, align the A-plane with the midline of the long axis of the infraspinatus.
4. Before starting the 3D sweep, tilt the probe over the rotator cuff tendons to minimize anisotropy over the area of interest. Use large amounts of gel to ensure good acoustic coupling in the peripheral part of the scanhead.
5. After selecting large sweep angles, start 3D sweep. During each sweep determine if the structure of interest (either the subscapularis, or the supraspinas, or the infraspinatus-teres minor complex) has been included in the dataset. If not, repeat the sweep.
6. Press Save 3D Volume to store.
7. Review data using MPR and postprocessing algorithms provided by the QLAB 3DQ GI software.

Clinical impact of new volume imaging approach
- With volume ultrasound, MPR reconstruction and, particularly, the C-plane can enable identification of new details of tendon morphology not provided by conventional 2D ultrasound (Image A).
- In full-thickness tears of the rotator cuff, volume ultrasound can contribute to better delineation the tear width and the amount of tendon retraction (Image B).
- In rheumatologic disorders, volume ultrasound may help to quantify the amount of effusion or synovitis distending the glenohumeral joint recesses and the SASD bursa. Volume assessment of the synovial space may open new perspectives to compare follow-up exams and assess the response to therapy (Image C).
- The stored dataset provides a permanent record of the exam, for second reading, review or audit.
**Case study**

A 68-year-old male presented with shoulder pain and disability. Conventional 2D ultrasound diagnosed the presence of a full-thickness tear of the supraspinatus tendon. Volume ultrasound confirmed the presence of the tear and allowed effective measurement of its width and retraction.

Image A. Normal subscapularis tendon (a, b, c). This tendon has a multipennate structure (arrows) made of multiple bundles of fibers (arrows) converging toward the lesser tuberosity (Lt). This complex arrangement of fibers can be appreciated on GRE T2* MR imaging (a), anatomic specimen (b) and volume US with MPR (c). Normal infraspinatus and teres minor tendons (d, e). Anatomic specimen (d) and volume ultrasound image (e) demonstrate the paired tendons of these two muscles as they converge toward the posterior aspect of the greater tuberosity.

Image B. Full-thickness tear of the supraspinatus tendon. Long axis 2D ultrasound (a) and volume ultrasound scan (b) over the ruptured tendon demonstrate some torn fibers (1) inserted into the greater tuberosity (GT), the gap of the tear filled with fluid (2) and the retracted tendon (3). In B, the tear width is better delineated on the C-plane.
22. **Volume imaging of the shoulder (rotator cuff) continued**

Image A. Long axis view.

Image B. Width view (C-plane).

Image C. Volume estimation of the posterior recess of the glenohumeral joint. (a) Posterior transverse 2D ultrasound image reveals anechoic effusion (asterisk) distending the recess and surrounding the posterior labrum (arrow), just deep to the infraspinatus tendon. (b, c, d) After postprocessing, the posterior recess is rendered as a red object and it is shown (asterisk) at different view angles. Quantification of the fluid content was also feasible (not shown). HH, Humeral head.

Image D. (a) Long axis 2D ultrasound and corresponding (b) volume ultrasound image oriented on the C-plane of a small full-thickness tear of the supraspinatus tendon. With appropriate multiplanar reconstruction, volume ultrasound allows adequate delineation of the tear width and the amount of tendon retraction from the greater tuberosity (GT).