Comparison of Axial Reconstructed Ultrasonographic Images From Three-dimensional Data Volumes and Computed Tomographic Scans in the Documentation and Detection of Liver Lesions

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Objective. To compare axial reconstructed ultrasonographic images from three-dimensional data volumes and conventional computed tomographic scans in documentation and detection of liver lesions. Methods. The livers of 23 patients were examined by a multifrequency curved array transducer to acquire three-dimensional data volumes and by conventional computed tomography. The ultrasonographic device was equipped with three-dimensional ultrasonographic technology allowing for real-time parallel movement in every plane within an acquired data volume. Axial ultrasonographic images reconstructed from three-dimensional data volumes were compared with conventional computed tomographic scans. Results. When both methods were taken together, a total of 51 different liver lesions could be detected. Reconstructed ultrasonographic images depicted 44 (86%) of 51 lesions, and computed tomographic scans showed 46 (90%) of 51 lesions. Compared with computed tomography, ultrasonography depicted 5 additional lesions in 3 of the patients (4 hemangiomas and 1 unspecified lesion), whereas 7 lesions were missed in another 4 patients (4 metastases, 2 calcifications, and 1 cyst). The Pearson correlation coefficient between ultrasonography and computed tomography was $r = 0.84$ ($P < .001$). Conclusions. Our study shows that ultrasonographic images can be effectively reconstructed from three-dimensional data volumes. With respect to documentation and detection of liver lesions, the results obtained by three-dimensional ultrasonography appear comparable with those obtained by conventional computed tomography. However, several technical and procedural limitations have to be respected. Key words: ultrasonography, three-dimensional; ultrasonography, technology; ultrasonography, comparative studies; liver, computed tomography; liver neoplasms.

During the past few years the performance of ultrasonographic imaging systems has greatly improved. Most notably, the availability of programmable high-speed processors gave rise to complex image-processing systems allowing for on-line and real-time image analysis. One recent development was the integration of interactive three-dimensional imaging technology in ultrasonographic devices (three-dimensional ultrasonography [3DUS]). This technology allows for volume data acquisition, reconstruction, and multiformat display, all in real time. In the course of an ultrasonographic examination of the abdomen, three-dimensional (3D) imaging of the liver offers several new options. In diagnostic practice, 3DUS of liver tumors...
(surface mode) may facilitate decisions on surgical liver resection by spatial visualization of vascular landmarks. In addition, the importance of 3DUS in the estimation of liver metastases (volume mode) has considerably increased in patients receiving oncologic follow-up. Three-dimensional ultrasonography is also helpful for biotic procedures, allowing for correct positioning of the needle in relation to the respective lesion. However, the various possible applications of 3DUS need to be assessed for their specific diagnostic and clinical value. In this study, we evaluated the diagnostic potential of 3DUS in the documentation and detection of liver lesions by comparing axial reconstructed ultrasonographic images with conventional computed tomographic scans.

Materials and Methods

In our study a total of 23 consecutive patients (12 men and 11 women; mean age, 59 ± 14 years [range, 28–75 years]; mean body mass index, 23 ± 4 kg/m² [range, 18–28 kg/m²]) were prospectively examined after informed consent was obtained. All patients were followed up by the department of internal medicine and screened for the presence of liver lesions. Therefore, the study group included patients with and without liver lesions. Patients having more than 6 liver lesions were not included in the study. The respective diagnoses were obtained by histologic analysis, clinical follow-up, and additional imaging procedures. Liver lesions shown by computed tomography (CT) were characterized according to the criteria of Muramatsu et al and Honda et al. Lesions classified as unspecified and benign were confirmed by clinical follow-up of the respective patients for at least 6 months. Additional imaging procedures were magnetic resonance imaging and scintigraphy. Three-dimensional ultrasonography was performed directly after CT by 2 different examiners (M.J. and C.K.) who were blinded to the CT results. To allow direct comparison between computed tomographic scans and axial reconstructed ultrasonographic images of the liver, all patients were examined according to standardized ultrasonographic and computed tomographic protocols.

Ultrasonographic examination was performed using a standard ultrasonographic device (Siemens Medical Systems, Issaquah, WA) equipped with interactive 3D technology (3-Scape). The data volumes (DV) were acquired during breath holding with a Siemens 3.5C40H multifrequency curved array transducer (2.77–5.14 MHz) without external positioning devices. Image registration and motion estimation algorithms based on the echo information in adjacent slices were used to control the transducer position. Image parameters (depth, gain, and transmit power) were optimized for each patient. In a few patients with a high body mass index, the upper part of the liver along the costal arch was scanned during deep inspiration in the left lateral decubitus patient position. The examination started with a transverse scan. The transducer was placed on the skin in a sagittal position and then steadily and slowly (10 mm/s) moved along the costal arch from the right to the left liver lobe. Acquisition of each DV set took approximately 20 seconds. Depending on the liver size, a second or even a third transverse scan was performed in a scanning line caudal from the traces of the previous scan in the sonographic gel. In addition, 2 craniocaudal scans with the transducer placed in a transverse position were performed to acquire the data from each liver lobe separately. The number of DVs acquired from each patient was given by the respective liver size. The DVs were digitally stored for further analysis. Complete revision of a single 3D DV took approximately 4 minutes.

All computed tomographic examinations were performed with a Somatom Plus VD 30 system (Siemens). After a digital scout view, unenhanced and enhanced scans were conducted with contiguous 8-mm-thick sections at 120 kV (peak) and 330 mA (scan time, 2 × 1 second; reconstruction algorithm, “soft”). We generally adopted a biphasic modality of contrast medium injection (Ultravist; Schering AG, Berlin, Germany) divided into a first bolus of 25 mL at 1 mL/s followed by infusion of 75 mL at a 0.3-mL/s flow rate. The shortest possible total liver scan time was 2 to 3 minutes. All precontrast and postcontrast scans were obtained in the craniocaudal direction and during breath holding.

Computed tomographic images and 3D DVs were each reviewed by 2 independent observers (CT, M.J. and C.K.; 3DUS, M.B. and M.K.), who were blinded to the results of the other imaging modality. Single reconstructed ultrasonographic images were evaluated directly on the ultrasonographic device with a fixed effective thickness of the contiguous image intervals. Artifacts (i.e.,
pulsation or step formation) were classified as acceptable (no or negligible artifacts) or unacceptable (severe artifacts). Statistical analysis included interobserver variability; moreover, the correlation coefficient (axial reconstructed ultrasonographic images versus computed tomographic scans) was determined according to the Pearson method.

Results

With conventional CT and 3DUS taken together, in 23 patients a total of 51 different liver lesions could be detected (Figs. 1 and 2). The lesions were specified by histologic analysis (2 patients with hepatocellular carcinomas) or by further CT, clinical follow-up for at least 6 months, or both (9 patients with metastases, 2 with cysts, 2 with calcifications, and 2 with unspecified lesions). Magnetic resonance imaging, scintigraphy, or both were necessary in 6 cases (2 cysts, 2 hemangiomas, and 2 focal nodular hyperplasias). A single diagnosis was obtained in 13 of 23 patients, whereas coincidence of 2 diagnoses occurred in 5 of 23 patients.

The lesions were classified as metastases (n = 27), hemangiomas (n = 6), cysts (n = 6), hepatocellular carcinomas (n = 5), calcifications (n = 3), focal nodular hyperplasias (n = 2), and unspecified lesions (n = 2). In 5 patients neither 3DUS nor conventional CT showed liver lesions. The sizes of the lesions were as follows: less than 1 cm (n = 7), 1 to 2 cm (n = 17), 2 to 3 cm (n = 11), 3 to 4 cm (n = 7), and greater than 4 cm (n = 9).

Axial reconstructed ultrasonographic images depicted 44 (86%) of 51 lesions, and CT showed 46 (90%) of 51 lesions (Table 1). The Pearson correlation coefficient was $r = 0.84$ ($P < .001$). The interobserver variability was 3.7% ± 0.5%, yielding a $\kappa$ value of 0.96.

The numbers of acquired 3D DVs were as follows: 1 DV in 2 patients, 2 DVs in 4 patients, 3 DVs in 11 patients, 4 DVs in 3 patients, and 5 or more DVs in 3 patients. In all patients the acquired DVs allowed for a direct comparison with the corresponding computed tomographic scans. However, in a limited number of patients, we were not able to adequately document the capsule of the liver (cranial, n = 6; caudal, n = 2) because of respiration artifacts, obesity, or both.

Compared with CT, 3DUS depicted 5 additional lesions in 3 patients (4 hemangiomas and 1 unspecified lesion). All the hemangiomas could be confirmed by magnetic resonance imaging; however, the unspecified lesion (which was seen only on ultrasonography) remained etiologically unclear but had a constant size during sonographic follow-up for 6 months. Two of the hemangiomas were smaller than 1 cm; the other 2 had diameters of 1 to 2 cm and were hyperechoic. The unspecified lesion was smaller than 1 cm and was hypechoic.

On the other hand, 3DUS missed 7 lesions in 4 patients compared with conventional CT. These lesions included 4 metastases in 3 patients, 1 of whom had 2 additional calcifications, and the remaining lesion was a cyst. The calcifications, the cyst, and 2 of the metastases were smaller than 1 cm; the remaining 2 metastases were 1 to 2 cm.

Figure 1. High-speed processing power allows real-time 3D data acquisition (A) and transverse reconstruction of an ultrasonographic image showing nodular hyperplasia (B).

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Discussion

To date, ultrasonography and CT are the most common diagnostic modalities in clinical routines. Besides the accepted advantages of ultrasonography (availability, low costs, and lack of radiation), it should be noted also that the method is largely operator dependent. Another problem is the current manner of documenting dynamic processes, because the acquired data are mostly stored as static ultrasonographic images. Three-dimensional ultrasonographic technology might be a step forward to overcome the aforementioned limitations, because it allows for a real-time or retrospective analysis of an acquired DV in any activated plane.

Compared with other 3D techniques that have been used in liver diagnostics, especially for volume measurements,\textsuperscript{12,13} the 3DUS technology applied in this study requires neither external positioning devices nor special 3D transducers; therefore, the acquisition of 3D data is easy to perform and takes only a few minutes. On the other hand, systems with special 3D transducers and external positioning devices are expected to yield higher accuracy than the 3DUS technology discussed here.\textsuperscript{14} The resolution of the smallest volume element (voxel) in 3DUS with a 3.5C40H transducer at a 14-cm depth is 0.547 mm (edge length). Because of the acoustic properties of the transducer, however, the elevation thickness at 14 cm is around 5 mm (at –6 dB). This means that in the $z$-plane the physical resolution is limited by transducer performance. Therefore, the voxel size in ultrasonography is about 1.49 mm\textsuperscript{3} (0.547 $\times$ 0.547 $\times$ 5 mm). Important parameters for calculating voxel size in CT are field of view, matrix, and slice thickness. The field of view in our patients was 300 mm, and the matrix of our CT scanner is 512 $\times$ 512, giving a quotient of 0.586 mm. Therefore, the voxel size in CT is 2.75 mm\textsuperscript{3} (0.586 $\times$ 0.586 $\times$ 8 mm). Because of the similar resolution of both modalities, it seems conceivable that axial reconstructed ultrasonographic images from 3D DVs may be compared with computed tomographic scans. However, in all of our reconstructed ultrasonographic images, pulsation artifacts could be noticed in the subdiaphragmatic regions caused by heartbeats. Another artifact was edge formation because of inconstant mov-

Table 1. Number of Liver Lesions Shown on Reconstructed Ultrasonographic Images and Computed Tomographic Scans

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Reconstructed Ultrasonographic Images From 3D DVs</th>
<th>Conventional Computed Tomographic Scans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metastasis</td>
<td>23</td>
<td>27</td>
</tr>
<tr>
<td>HCC</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Cyst</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Hemangioma</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>FNH</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Calcification</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Unspecified</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>46</td>
</tr>
</tbody>
</table>

Values are numbers of lesions. FNH indicates focal nodular hyperplasia; and HCC, hepatocellular carcinoma.

Figure 2. A, Transverse reconstructed ultrasonographic image from the 3D DV of a patient with a solitary metastasis. B, Corresponding computed tomographic scan.
ing of the transducer. Because in our study the image quality was sufficiently high to allow for a visual analysis of all the DVs acquired, the aforementioned artifacts could be neglected. All other current artifacts, i.e., sound absorption by intestinal gas and mirror effects, are well known from conventional ultrasonography and not specific to 3D DV acquisition.

One limitation of our study was the incomplete acquisition of DVs from the capsule of the liver in a few cases. That may be circumvented by scanning each liver lobe transversely and longitudinally. Moreover, it should be noted that the computed tomographic scanning protocol used in our preliminary study cannot be considered the state of the art in the current era of multidetector CT. Nevertheless, keeping this limitation in mind, our study could serve as a proof of concept. Finally, our study was limited by the fact that specification of the detected liver lesions was not always confirmed by histologic analysis, mainly because of our internal diagnostic procedure, which stipulates that primarily benign classified lesions should be specified as a first line by other imaging modalities or their clinical course and not by invasive procedures. In cases of known malignant lesions, the main clinical interest is to get reproducible information about the number and size of such lesions in the follow-up to facilitate the decision on chemotherapy.

In conclusion, our study suggests that ultrasonographic images reconstructed from 3D DVs reach a high level of accuracy compared with computed tomographic scans. However, potentially malignant liver lesions may be missed by that method; therefore, CT should be considered as the modality of choice when screening for malignancy. On the other hand, our data show that in cases of ultrasonographically visible malignant lesions, 3DUS offers an inexpensive and easy-to-perform approach in the follow-up of liver tumors.

References


