3-D Ultrasound for the Evaluation of Malignant Disease

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In the last few years there has been increasing interest in the development of 3-D display in medical imaging techniques.[1,2] 3-D imaging is capable of enhancing the anatomic information of the images. This technique facilitates the localization of normal and pathologic structures and the understanding of spatial relationships. Computer reconstructed 3-D views of computed tomography (CT) and magnetic resonance imaging (MRI) have improved image interpretation by clinicians especially in reconstructive and orthopaedic surgery.[3,4] Although the advantageous features of 3-D display are well recognized for radiologic imaging methods, 3-D data acquisition in ultrasonography has not yet found broad clinical acceptance. This has been mainly due to the lack of hardware appropriate for clinical use and the time required for data processing of high resolution 3-D images. However, recently some experimental solutions for sonographic data acquisition as well as more rapid computer systems have been developed.[5-7]

PATIENTS AND METHODS

3-D data acquisition was accomplished using a Combison 530 ultrasound unit (Kretztechnik, Austria) equipped with three 3-D transducers for transcutaneous or transrectal application.

Transcutaneous 3-D ultrasound was performed in 47 patients for the evaluation of various neoplasms. These patients comprised 19 females and 28 males with a mean age of 59 years (range 32–83 years). In all patients a conventional 2-D examination preceded the 3-D ultrasound. After identification of a suspicious lesion with the conventional technique, at least two volume scans were recorded for subsequent evaluation. Volume scanning with this probe is achieved by mechanical rotation of the transducer by a stepping motor the scan plane being swept over the region of interest (Fig. 1). Recording a multitude of serial planes results in a pyramid-shaped volume scan with a maximum volume of 2.5 L. Volume scans can be acquired in 4–8 seconds dependent on the selected sweep angle (0–90°) and the number of serial scan planes recorded (50–250).

3-D endosonography was applied to 93 patients for preoperative staging of rectal cancer. The examinations were performed on an outpatient basis without sedation or anesthesia. Before the examination the rectum was cleaned by a phosphate enema. With the patient in genucubital position, the 3-D endoprobe was introduced blindly into the rectum. To achieve an acoustic interface between the transducer and the rectal wall, a latex balloon attached to the tip of the probe was filled with 30–50 ml of deaerated water. Prior to volume scanning a conventional examination (360° display) was performed by withdrawing the probe to define the region of interest.

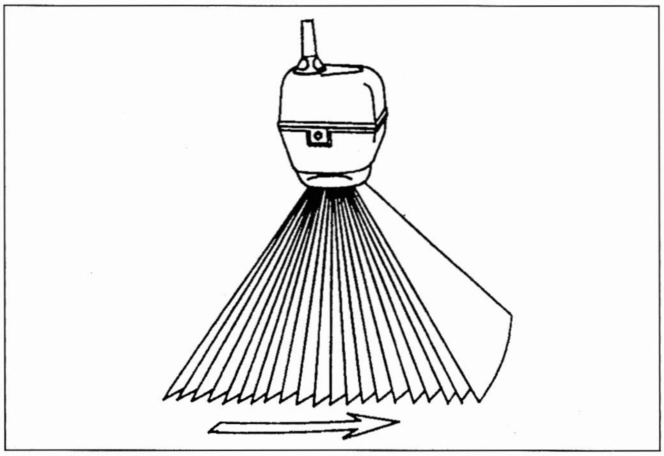

Figure 1. Data acquisition with a 3-D ultrasound transducer.

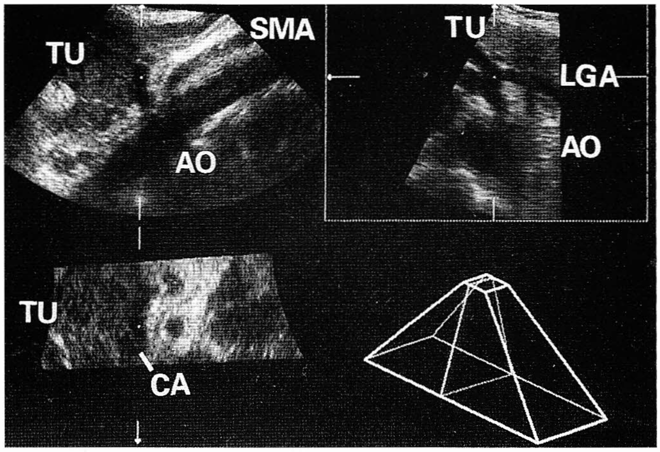

Figure 2. Abdominal 3-D ultrasound of a pancreatic carcinoma (Section display). (Tu= Tumor, Pa=Pancreas, Ao=Aorta, SMA= superior mesenteric artery, CA= coeliac axis, LGA=left gastric artery)

Non-stenotic tumors were examined using a rigid 3-D ultrasound probe (VRW) equipped with a bifocal multiplane transducer (7.5/10 MHz). This transducer provides a 360° transversal and 100° longitudinal scan angle. The radial scan plane of the transducer displays a conventional 360° image of the rectal wall and the adjacent tissues. Volume scans are generated by recording up to 250 serial sagittal scan planes which results in a pyramid shape of the scanned volume.

In patients with obstructing tumors a rigid 3-D frontfire endoprobe (VEW) with a 7,5/10 MHz tranducer and a 100° anterior scan plane was utilized. Volume scanning with this probe is achieved by 360° rotation of the scan plane along the longitudinal axis of the instrument. Consequently, the scan volume resembles a truncated cone. The infiltration depth of the tumor was classified according to the layer interpretation described by Hildebrandt and Feifel.[8]

All volume data were stored on a hard disk and were subsequently processed on the Combison 530 workstation. 3-D image analysis allowed display of the digitized information in the section display or the volume display. The former enables visualization of the acquired volume scans along three orthogonal planes i.e., sagittal, transverse, and the C-plane (parallel to the surface of the transducer). The latter displays a 3-D reconstruction of the data based on selected perpendicular scans which provides a realistic impression of the three-dimensionality of the image. In both modes it is possible to cycle through each 2-D scan plane which permits meticulous examination of the images. The diagnostic relevance of 3-D imaging was assessed independently by two investigators.

RESULTS

A total of 126 volume scans were recorded in 47 patients undergoing transcutaneous 3-D ultrasound. Indications for the examination included evaluation of hepatic lesions (n=26), pancreatic cancer (n=8), sarcoma (n=7), and breast cancer (n=6). The mean examination time for 3-D ultrasound including acquisition of at least two volume scans in each patient was 8 minutes (range 3–15 min.). Further 18 minutes were required on average (range10–25 min.) for 3-D image analysis after the examination using the section and the volume display.

The sectional display proved to be extremely helpful for the evaluation of anatomical details because normal and pathologic structures could be visualized simultaneously in three planes (Fig. 2). The C-plane of this mode provides scan planes parallel or oblique to the transducer's surface which are not obtained with conventional transducers. Integration of the information delivered by three perpendicular views of the region of interest facilitated the assessment of the sonographic findings, especially in complex anatomical situations. The relative position of tumors to vessels and other landmark-structures was often delineated more clearly. The improved ability to depict the relationship of the tumor to major vessels and other relevant structures was best appreciated in hepatic metastases, tumors involving the porta hepatis, and pancreatic carcinoma (Fig. 3, 4). In contrast to 2-D scans the 3-D volume display provided a spatially oriented display of the image position. By 3-D volume reconstruction realistic views of the anatomy were generated which enhanced the understanding of the localization of the tumor and the relationship to adjacent organs. 3-D ultrasound confirmed the findings seen on the 2-D scans in all patients. Compared to conventional ultrasonography, the 3-D technique improved the diagnostic confidence of the investigator in 58% of the patients. Additional information on anatomic details based solely on 3-D findings were obtained in 19% of the patients.

3-D endosonography enabled correct classification of the tumor infiltration depth in 86% of patients with non-obstructing tumors (Table 1). Evaluation of the volume data changed the T-classification in two of the patients. In one patient with questionable infiltration of the prostate, 3-D display clearly showed penetration of the tumor into the gland. In another patient, 3-D image analysis evidenced tumor infiltration into the submucosa, although an adenoma had been diagnosed in the conventional examination. The accuracy rate in the determination of metastatic lymph node involvement was 75%. Compared to the conventional real-time examination, 3-D image analysis demonstrated additional lymph nodes in six patients. The section mode proved to be very helpful for the delineation of small lymph nodes and other minor details (Fig. 5). The volume mode provided a spatially oriented display which closely resembled the original anatomy. This was especially valuable to improve the understanding of the anatomy and the relation of the tumor to juxtaposed structures (Fig. 6). In our subjective experience 3-D endosonography facilitated the interpretation of the ultrasound images and increased the diagnostic confidence of the operator in approximately 60% of the cases.

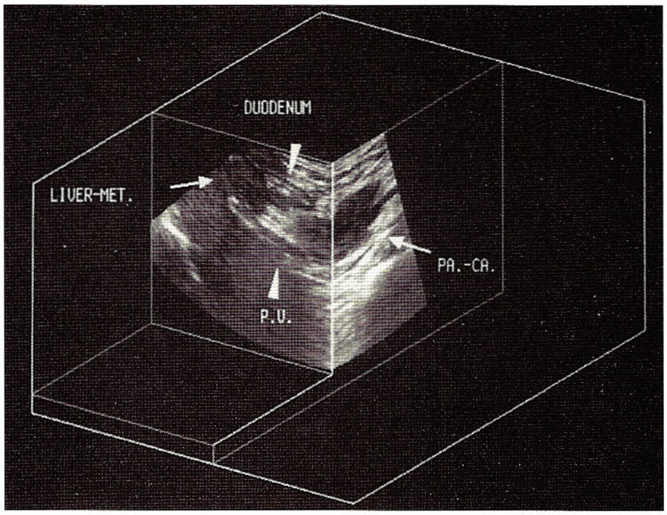

Figure 3. Abdominal 3-D ultrasound of pancreatic carcinoma (Volume display). (P.V. = portal vein)

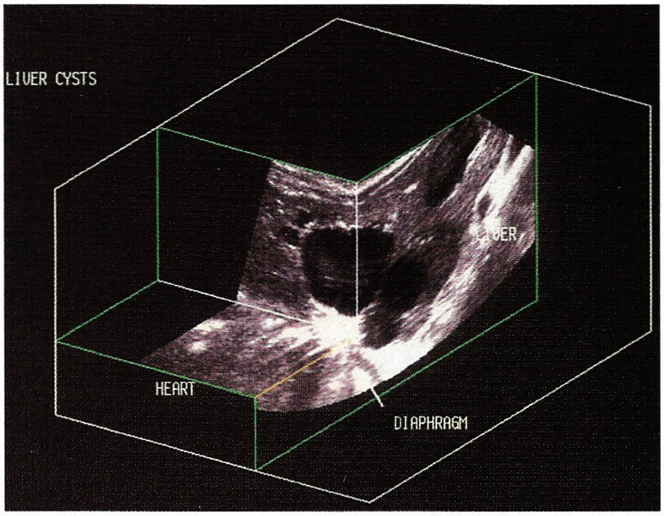

Figure 4. Volume scan of multiple liver cyst.

Table 1. Correlation of 3-D endosonography and histopathology in non-stenotic rectal cancer (n = 41)

	uT0	uT1	uT2	uT3	uT4
pT0	10				
pT1	1	4	1		
pT2			12	1	
pT3		1	2	6	
pT4					3

Table 2. Correlation between 3-D endosonography and histopathology in 18 patients with obstructing rectal cancer

	uT1	uT2	uT3	uT4
pT1	-			
pT2		3	3	
pT3		1	8	
pT4				3

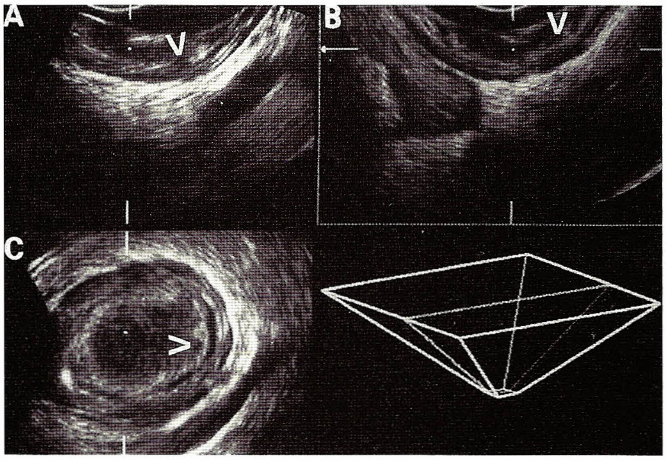

Figure 5. Section display of a small rectal tumor reveals infiltration (arrow) of the submucosa (uT1) in all three planes. The C-plane is parallel to the surface of the transducer.

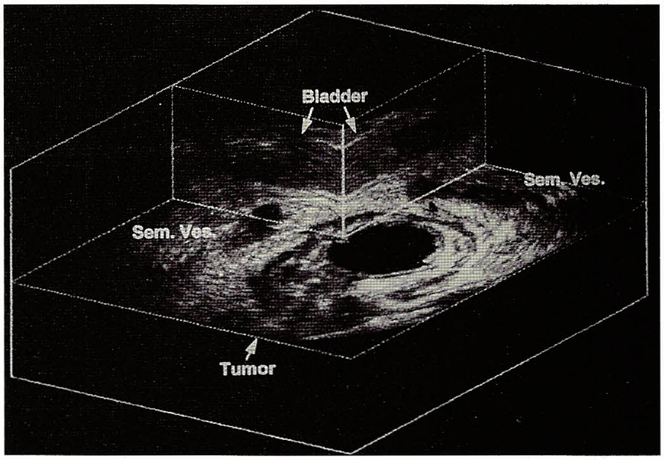

Figure 6. Volume display provides a 3-D view of a rectal carcinoma infiltrating the perirectal tissue and juxtaposed structures. (Tu = tumor, Sem. Ves. = seminal vesicle)

3-D endosonography of obstructing rectal tumors was performed in 26 patients. None of the tumors was accessible to conventional transrectal ultrasound due to a severe stenosis. Nonetheless, the 3-D frontfire transducer provided full visualization of the rectal stenosis in all cases by reconstruction of the scan plane in front of the transducer (Fig. 7a-b). The tumor infiltration depth was correctly determined in 14 of 18 patients with obstructing rectal cancer (Table 2). The accuracy in the determination of the infiltration depth was 78%. Lymph nodes were detected in 10 patients and histopathological examination of lymph nodes was possible in all cases. Metastatic involvement of the lymph nodes was found in eight patients resulting in an accuracy of 75%.

DISCUSSION

Especially in regions with a complex anatomy it is often difficult to integrate the

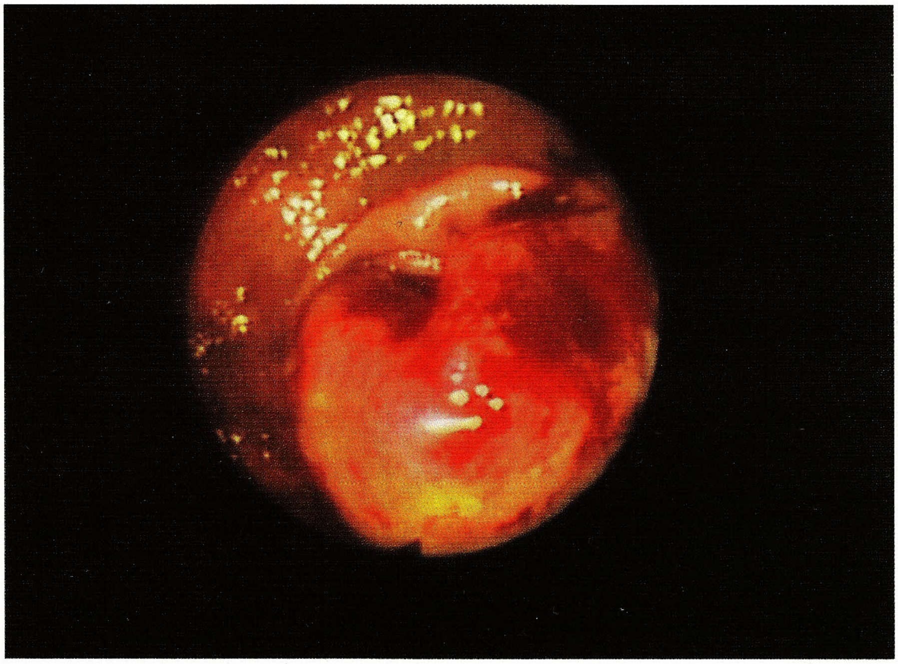

Figure 7a. Endoscopic view of a carcinoma of the rectum causing a filiform stenosis.

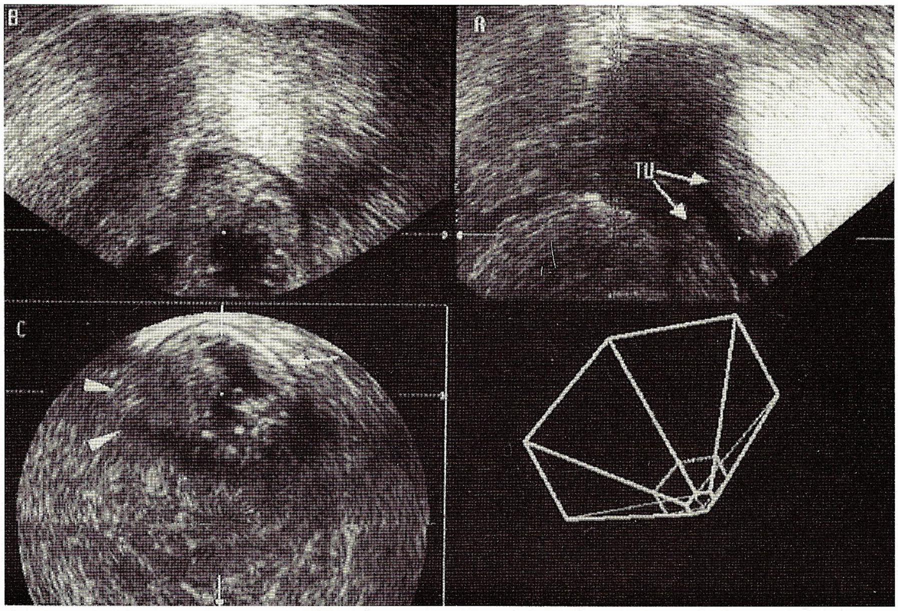

Figure 7b. The frontfire transducer allows visualization of the tumor (TU) in three planes. The C-plane is a reconstructed plane in front of the transducer and compares favourably to the endoscopic view. Infiltration of the perirectal fat is demonstrated (arrow).

information from individual 2-D ultrasound images to produce a mental impression of the real anatomy. To overcome the limitations of conventional ultrasound, some 3-D ultrasound systems have been developed and used in experimental and preclinical studies. In the meantime, there are also few reports on the clinical application of 3-D ultrasound.[9-11] In most of the studies 3-D ultrasound was ultilized for the evaluation of fetal malformations, although this technique seems also valuable for imaging of malignant disease.[12-15]

The first purpose of this study was to establish the clinical feasibility of 3-D ultrasound for imaging of malignant disease. The second was to investigate the capability of 3-D ultrasound to facilitate the imaging procedure and to improve the interpretation of the scans.

The Voluson 3-D ultrasound system offered a sophisticated technique for acquisition, processing, and display of 3-D data which seemed appropriate for clinical use. Recording of a volume scan required 5–10 seconds and was easily completed during a single breath hold. This is important because movements during the scanning process may cause artifacts that degrade the image significantly.

3-D image processing allowed display of 3-D data in two modes: section display depicts structures simultaneously in three orthogonal planes and provides previously unattainable planes. This technique overcomes anatomical limitations which restrict the orientation of the scanning planes. The volume display permits depiction of the data as a 3-D view, which closely resembles the original anatomy. 3-D views can be used to understand the spatial relationship between tumors and anatomic structures and give the surgeon important preoperative information that may optimize operation planning. In our experience, 3-D ultrasound facilitated the interpretation of the ultrasound scans and improved the diagnostic confidence in approximately 60% of the examinations. Additional information solely based on the 3-D display was obtained in 19% of the patients. These observations are comparable to those made in other non-gynecological studies. Wagner and coworkers found 3-D ultrasound superior to conventional ultrasound in 26 of 93 patients (28%) with hepatic disease.[16]

Endorectal ultrasonography has been extremely valuable for preoperative staging of rectal carcinoma. Consistently, accuracy rates of 90% have been reported in the determination of tumor invasion.[17-20] The accuracy in the assessment of lymph node involvement ranges from 75% to 85%.[20,21] However, clinical experience with endosonography has demonstrated that the interpretation of endosonography images is difficult. The accuracy of endosonography appears to be proportional to the experience of the observer.[22] One major problem is the assessment of small details in the bowel wall and the pararectal tissue. Cross sectioned blood vessels as well as the seminal vesicles may be confused with lymph nodes.

Assessment of borderline situations may be extremely difficult during a realtime examination. Furthermore, staging of advanced rectal cancer by conventional endosonography is often limited by the inability to pass the endoprobe beyond the tumor. 3-D endosonography seems capable of improving most of these problems. 3-D imaging expands the diagnostic value of endorectal ultrasound because previously unattainable planes and views become available. The section display proved to be particularly valuable for the identification of small lymph nodes and other subtle details. The volume display improved the understanding of the anatomy and the relation of the tumor to juxtaposed structures. The accuracy of 3-D endosonography in the classification of the tumor infiltration depth was 86%. Lymph node involvement was correctly determined in 75%. One major advantage of 3-D endosonography was the ability to visualize obstructing tumors by reconstruction of transversal scan planes in front of the transducer. The accuracy in the assessment of the infiltration depth of stenotic tumors was 78%. These figures may even improve with increasing experience, which has been also reported for conventional transrectal ultrasound.[17]

Besides improved image interpretation, 3-D ultrasound provides clear benefits with respect to documentation. Hard copies of sonograms have not been valuable to clinicians because they are more difficult to interpret than, e.g., comparable CT or MR images.[7] This problem is avoided with 3-D images because they provide spatially oriented pictures of the anatomy. Therefore it is possible to display standardized views, which reduces the operator dependence and increases the comparability of follow-up studies. The ability to reconstruct images from original data makes real-time reevaluation of the scan possible. This permits one to transfer the digitized information to specialists who can then review the findings and supply a second opinion. Furthermore the ability to simulate real-time examinations without patient offers new perspectives for medical education.

However there are some limitations of the 3-D technique. The maximum volume acquired with 3-D scanning may be too small to capture large targets entirely. Therefore cutoff of data may occur in the region of interest and can compromise the diagnostic information of the scan. Voluntary patient motion, as well as heart beat during the scanning process cause artifacts that may lead to misinterpretation of the findings. It is likely that these problems will be solved by technical advances and that 3-D ultrasound will become a valuable adjunct to conventional sonographic examinations. **STI**

REFERENCES

1. Fishman EK, Magid D, Ney DR, et al. Three-dimensional imaging. Radiology 1991;181: 321–37.
2. Wenzl R, Lehner R, Pateisky N, et al. Three-dimensional video endoscopy: clinical use in gynecological laparoscopy. Lancet 1994;344: 1621–2.
3. Fishman EK, Magid D, Ney DR, et al. Three dimensional imaging in orthopedics. Orthopedics 1988;13:1021–6.
4. Zonnefeld FW, Lobregt S, van der Meulen JHC. Three-dimensional imaging in craniofacial surgery. World J Surg 1989;13:328–42.
5. Fine D, Perring S, Herbetko J, et al. Three-dimensional (3-D) ultrasound imaging of the gallbladder and dilated biliary tree: reconstruction from real-time B-scans. Br J Radiol 1991; 64:1056–7.
6. Gillams A, Gardener J, Richards R, et al. Three-dimensional computed tomography cholangiography: a new technique for biliary tract imaging. Br J Radiol 1994;67:445–8.
7. Rankin RN, Fenster A, Downey DB, et al. Three dimensional sonographic reconstruction: techniques and diagnostic application. AJR 1993;161:695–702.
8. Hildebrandt U, Feifel G. Preoperative staging of rectal cancer by intrarectal ultrasound. Dis Colon Rectum 1985;28:42–6.
9. Hamper UM, Trapanotto V, Sheth S, et al. Three-dimensional US: preliminary clinical experience. Radiology 1994; 191:397–401.
10. Sohn CH, Stolz W, Kaufmann M, et al. Three-dimensional ultrasound imaging of benign and malignant breast tumors--initial clinical experiences. Geburtshilfe Frauenheilkd 1992;52:520–5.
11. Zoller WG, Liess H. 3-D ultrasound in gastroenterology. Bildgebung 1994;61:95–9.
12. Kelly IM, Gardener JE, Lees WR. Three-dimensional fetal ultrasound (letter). Lancet 1992;339:1062–4.
13. Steiner H, Staudach A, Spitzer D, et al. Does 3D sonography present new perspectives for gynecology and obstetrics? Geburtshilfe Frauenheilkd 1993;53:779–82.
14. Merz E, Bahlmann F, Weber G. Volume scanning in the evaluation of fetal malformations: a new dimension in prenatal diagnosis. Ultrasound Obstet Gynecol 1995;5:222–7.
15. Lee A, Kratochwil A, Deutinger J, et al. Three-dimensional ultrasound in diagnosing phocomelia. Ultrasound Obstet Gynecol 1995;5:238–40.
16. Wagner S, Gebel M, Bleck JS, et al. Clinical application of three-dimensional sonography in hepatobiliary disease. Imaging 1994;61:104–9.
17. Orrom WJ, Wong WD, Rothenberger DA, et al. Endorectal ultrasound in the perioperative staging of rectal tumors: a learning experience. Dis Colon Rectum 1990;33 654–9.
18. Glaser F, Layer G, Zuna I et al. Präoperative Beurteilung pararektaler Lymphknoten durch Ultraschall. Chirurg 1990;61:587–91.
19. Katsura Y, Yamada K, Ishizawa T, et al. Endorectal ultrasonography for the assessment of wall invasion and lymph node metastasis in rectal cancer. Dis Colon Rectum 1992; 35:362–8.
20. Beynon J, Mortensen NJ, Foy DMA, et al. Preoperative assessment of mesorectal lymph node involvement in rectal cancer. Br J Surg 1989;76:276–9.
21. Jochem RJ, Reading CC, Dozois RR, et al. Endorectal ultrasonographic staging of rectal carcinoma. Mayo Clin Proc 1990;65:1571–7.
22. Solomon MJ, McLeod RS, Cohen EK, et al. Reliability and validity studies of endoluminal ultrasonography for anorectal disorders. Dis Colon Rectum 1994;37:546–51.