Tridimensional (3D) endoscopic ultrasonography

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ABSTRACT

A review and update on 3D endoscopic ultrasonography is included regarding all of this technique’s aspects, technical details, and current indications. Images from our own clinical experience are presented.

Key words: Tridimensional. 3D echography or ultrasonography. 3D endoscopic ultrasonography. 3D endorectal ultrasonography. 3D laparoscopic ultrasonography.


TECHNICAL BACKGROUND

This “point of view” and update supplements a formerly published review (1).

The importance of tridimensional images as currently obtained by computerized tomography (CT) or magnetic resonance imaging (MRI) is unanimously endorsed, as they accurately reveal not only the precise location of a given lesion but also its relations to neighboring structures and organs, and more importantly the presence of continuity, particularly for infiltrating neoplastic lesions. Such images also allow an accurate measurement of volume in expanding lesions for therapy planning, which is particularly relevant in liver tumors undergoing alcoholization, antitumor substance injections, radiofrequency probes, shock waves, etc., as well as for response monitoring.

To obtain such tridimensional images all the information obtained from the study of a given volume is ordered by a software program allowing its spatial reconstruction. Obtaining these images using CT or MRI technology is a relatively simple procedure, as the scanning system in both instances is automatic, and the multiple slices from a selected area are sequentially captured, with no difficulties for the exploring physician.

Tridimensional image reconstruction is somewhat more complicated in ultrasonography, as slices are manually rather than automatically obtained when using conventional 2D ultrasounds, and hence image acquisition depends on the explorer’s skills. On the other hand the number of slices that may be acquired is incalculable with no established beginning or end, as one more slice may always be obtained. Despite these shortcomings a number of systems have been recently used to acquire 3D images using ultrasonography.

In order to understand this technique, such systems must be briefly described.

1. Hands-free system. The system initially used was a computer capable of ordering acquired images upon exploration completion using a given sequence for volumetric reconstruction. Images could be rotated around various axes for subsequent reconstruction.

   This system, used by Sackman in 1994 (2) for the study of the liver and pancreas, required a prolonged exploration time, as the information the device had to provide the computer with was complex and depended on the explorer’s skill to acquire a number of slices with no voids.

   This so-called hands-free system may on occasion use acoustic or magnetic sensors to aid in slice positioning for their subsequent interpretation.

2. Mechanical movement system. Systems currently in use employ mechanical transducers (VOLUSON 530 & 730, 3-5 MHz, with Vocal™ and Shell™ software). With these, the examiner no longer needs to obtain multiple slices in a given sequence and inclination, which in addition to skill also requires time. It is the probe itself that
incorporates a mechanical movement system to capture images for subsequent processing.

Two types of mechanical transducers are available. The first one is a transducer with a rotating mechanical system that allows the acquisition of multiple images for their subsequent processing by a computer. This system, which lacks the disadvantage entailed by manual slice acquisition, is particularly useful for small anatomical areas, as is the case with endorectal transducers (3). Another, more advanced mechanical transducer is that allowing the acquisition of a volumetric image from a truncated cone (VOLUSON 730, with a 75º angle) with its vertex located at the transducer.

Upon reaching the image or region of interest the examiner must leave the transducer static while the patient remains motionless, usually after a deep inspiration, to allow the probe to simultaneously scan two planes.

Images are captured and processed by a computer, which builds up a tridimensional reproduction. In the multiplanar mode three planes are scanned (longitudinal or sagittal-A, transverse-B, and coronal-C) and an orthogonal reconstruction is performed, which may be rotated around three axes (X, Y, Z).

The coronal plane may be important for the study of lithiasis in the bladder neck and distal major bile duct, especially in the presence of a choledochal cyst.

A 3D color-angiogram or power-Doppler scan is also possible. Vascularization indices, flow, volume of interest, etc., are relevant parameters.

In this multiplanar mode images may be seen in surface mode as well as in niche mode (inner view).

3. Transendoscopic miniprobes and 3D EUS. Fuji and Olympus have developed two mechanical transendoscopic miniprobe (TMP) systems performing radial and linear scans (FUJI, manual; Olympus, automatic, in two planes simultaneously) (Fig. 1).

Images may be processed by a computer, and reproduced in three dimensions (Figs. 2 and 3).

The system developed by Olympus is designated DPR (Dual-Plane Reconstruction); 3D images may be seen in surface or niche mode. Olympus and Pentax Hitachi have also developed a 3D echoendoscope.

INDICATIONS

In the field of gastroenterology (4) early papers reporting on the use of this technique assessed the potential accuracy in volume measurements as a future diagnostic possibility for this modality (5). Clinically, measuring the volume of an organ or lesion is a part of the diagnostic work-up and follow-up of many conditions. Conventional 2D ultrasonography, which represents a fast, cheap method for its determination, estimates volume by using the simple method of multiplying three diameters perpendicular to each other by 3/4.

This method, based on the assumption of such geometrical figures, entails an error margin that is on occasion significant in volume estimation. Tridimensional ultrasonography has been used with good results in the estimation of liver (6) and other (7-11) tumor volumes using planimetry, and has shown a greater accuracy versus conventional 2D ultrasounds and CT, which estimate volume by using the ellipse formula.

A step forward in the use of 3D ultrasonography in gastroenterology was its application for endoscopic ultrasounds (EUS) (12-15), even though volumes estimated using this method seem to be larger than real (15).

Thus Kallimani (16) published in 1994 the images acquired from eight patients with esophageal tumors using an Olympus echoendoscope, subsequently digitalized and processed in a PC by a certain software package.

Nishimura published in 1997 (17) some early results: 18 tumors resected from 21 patients. Tumors were esophageal, gastric, and colonic, and in their in vitro study their surface appearance was similar to macroscopic findings, which allowed an in-depth study of tumor infiltration. Clinical applicability had some limitations, but proved useful in the esophagus and rectum (18-20).

Some authors have tried the use of tridimensional ultrasounds in the preoperative evaluation of rectal tumors, and have considered this technique a valuable contribution for their assessment before therapy-related decision making (21,22). It is a well known fact that local relapse rates are high following rectal amputation with curative intent when perirectal fat is infiltrated (23). On the other hand, in rare advanced tumors, radiotherapy and chemotherapy increase resectability and survival. Recent studies have shown that nearly 70% of non-resectable tumors may be excised with curative intent following radiation therapy. Given all this, staging is very important for therapeutic decisions.

Tumor-induced stenosis (14%) has been suggested to be associated with poor prognosis. However, even though stenosing tumors are usually associated with advanced local disease, such piece of data does not represent a factor for poor prognosis when considered in isolation. On the other hand, obstruction alone does not warrant a preoperative management with radiation or chemotherapy. Given all this, an accurate preoperative assessment is essential for rectal cancer even in patients with obstructing tumors.

To this day, endorectal ultrasonography is the most accurate technique for its study. However, it cannot be applied for stenosing tumors that just will not allow passage of the probe through the stenosed area. Hence Hünerbein (24) studied 94 consecutive patients with rectal carcinoma. In 26 (27%) patients a stenosis was found that prevented an adequate exploration using endorectal ultrasound, and all 26 successfully underwent a 3D endorectal ultrasonography procedure that allowed tumor and stenosis visualization in all cases. Tridimensional endosonography correctly diagnosed infiltration extent in 78% of
patients, that is in 18 patients, and thus revealed three cases with an invaded muscularis propria (T2), eight cases where the tumor also involved perirectal fat (T3), and finally three patients with invaded neighboring organs (T4). The capability to demonstrate the presence of perirectal adenopathies was 75%. In eight patients the obstruction was accurately attributed by the 3D endosonogram to extrinsic lesions developed after surgery. It should be pointed out that despite the fact that lesion size ranged from 3 to 6 cm CT scanning had only revealed them in 6 cases. All eight patients saw their diagnosis confirmed by a biopsy guided with this same technique.

These results are very important, as they demonstrate that this technique is useful to assess tumor infiltration extent even in cases with stenosing tumors (14%) not allowing passage of the probe, and its assessment allows a change in therapeutic attitude for a number of patients (24,25).

Its application to the study of pancreatic and biliary conditions has been recently examined with the use of intraductal probes (26,27); while results are inconclusive as yet, this will open a new path for research.

The usefulness (28) of 3D intraductal ultrasonography for bile-duct carcinoma staging has also been investigated, but in a small number of patients. Thus, in a recent work a number of patients with extrahepatic bile-duct carcinoma were preoperatively assessed. All underwent an intraductal sonographic study using both conventional and 3D ultrasonography to assess right hepatic artery, vena porta, and pancreatic parenchyma invasion prior to resection. Results were then compared to histological information as provided by resected specimens. Tridimensional ultrasonography informed on right hepatic artery invasion in 88% of cases, on vena porta invasion in 100%, and on pancreatic parenchyma invasion in 100% of cases, while conventional intraductal ultrasounds pro-

Fig. 1. (A) A juxta-anal rectal lesion (adenocarcinoma) with a 15-mm greater diameter over which a 20-MHz MP is placed. (B) A radial image, (C) and an automatic radial-linear image are acquired that reveal a primary mucosal involvement, with submucosal layer displacement and an unscathed muscularis propria. (D) Mucous adenocarcinoma, T1 N0.
vided such information in only 88% for all three assessed parameters. These findings led the authors to conclude—despite the scarce number of cases studied—that 3D endoscopic intraductal ultrasonography is useful in the staging of bile-duct carcinoma.

Finally, some authors, including Kavic (29), state that the application of 3D ultrasounds in laparoscopic surgery may be glimpsed on the horizon, as this modality can safely provide accurate, real-time information on anatomical structures in the absence of ionizing radiation and with a relatively low cost (29,30).

TRIDIMENSIONAL ENDOANORECTAL ULTRASONOGRAPHY

Tridimensional ultrasounds have been particularly used in clinical practice for endoanorectal examination (31,32). A benefit provided by this technique—which shares with conventional endoanorectal sonography its good tolerability by patients and the scarce extent of preparation needed—is indeed fast image acquisition. In bidimensional endoanal echography the transducer must be repeatedly entered and withdrawn so that the explorer may obtain, following a number of radial slices, a spatial composition of the region of interest. In tridimensional sonography it is the transducer itself that performs the scanning, and provides—with no need for the patient to be present then—radial and longitudinal slices as well as a planimetric and volumetric study.

Indications for anorectal conditions include:
1. The study of perianal fistulas.
2. The study of incontinence for sphincter assessment.
3. The study of rectal tumors for staging.
4. The study of perirectal masses.

In the study of perianal fistulas the use of 3D ultrasounds is extremely useful. In a recent study reported by Ratto in 2005, where 112 patients with anal fistula were examined and explored using 3D EUS, a high consisten-

Fig. 2. (A and B) A 10-mm antral submucosal lesion (C) which undergoes a radial echoendoscopy using a 20-MHz MP; an echogenic image is seen in the submucosa layer with a non-involved muscularis propria, which is consistent with a fibrolipoma; (D) this is much better revealed by tridimensional ultrasonography.
The accuracy of the preoperative exam allowed the author to cure fistulas in 98% of patients. Continence was preserved in all cases. The author concluded that such accuracy regarding the relationships of fistular tracts to sphincters during the preoperative study allowed him to select a surgical procedure that would preserve sphincters and ensure subsequent continence.

Filling of fistulas using hydrogen peroxide by injecting this substance through the external fistular orifice may be useful for complex cases, even if no benefits derive in some studies (34). A number of studies compared the efficacy of tridimensional endoanal ultrasonography and endoanal MRI by infusing hydrogen peroxide into the fistula, and found similar results with both techniques (35,36).

Sphincter assessment, essential in the diagnosis of incontinence, also benefits from this technique (37). In 2005 Regadas studied 74 patients who underwent 3D EUS, and concluded that this technique showed anatomical differences in the anal canal between males and females regarding the external anal sphincter, which explains the higher rate of pelvic floor disorders seen in women versus men (38). Sphincter disturbances may be demonstrated by EUS and 3D EUS. However, 3D EUS increases the diagnostic yield for sphincter lesions (39). The higher accuracy provided 3D EUS has recently allowed Gosselink to demonstrate changes in the external anal sphincter of 57% of patients with rectal amputation and ileoanal or coloanal anastomosis, but this author found no relationship between these changes and the procedure’s functional outcome (40). External anal sphincter atrophy, which shows poor results following surgery, may be detected by endoanal MRI, but not endoanal sonography.

CT and MRI are excellent scanning modalities to assess disease at a distance, but not so much so when evaluating local characteristics such as invasion extent or relationship to neighboring viscera, adenopathies, etc. (41).
is here that ultrasonography meets one of its indications (42). Conventional endoanorectal sonography is the technique of choice to assess infiltration extent for non-stenosing rectal tumors, and to reveal their related adenopathies. Tumor infiltration extent in the rectal wall is detected in around 80-90% of cases, and adenopathies in 70-80%. However, experience is essential on the examiner’s side to interpret radial images, and interpretation may be erroneous in “borderline” cases even by experienced physicians (43). On the other hand, given that correct staging is crucial for the management and prognosis of rectal cancer, and that sphincter-preserving therapies have increased for rectal tumors during the past few years, tridimensional images have been used with hope in the study of these malignancies. However, to date, studies attempting to assess the efficacy of both techniques have found similar results. Results have not reached statistical significance in a number of studies comparing these two modalities, but found a greater capability to assess rectal wall infiltration—both for T2 and T3 tumors—and to detect adenopathies with 3D EUS (44,45). Christensen recently claimed that in anal canal carcinoma tridimensional endoanal ultrasonography increases adenopathy detection rates when compared to conventional endoanal ultrasonography, but further studies are needed (46). The problem posed by infiltration and adenopathy monitoring in rectal tumors after preoperative therapy with radiation therapy or chemotherapy has not been accurately approached with this technique, hence no conclusions may be drawn. Combined PET and CT might well represent a step forward.

Endoanal US has also been compared to endoanal MRI in the study of the normal anal canal and rectal tumors (47-49).


REFERENCES