Tridimensional (3D) Endoscopic Ultrasound – a Pictorial Review

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Abstract

Tridimensional endoscopic ultrasound (3D-EUS) offers a better understanding of the spatial relations of examined lesions and allowing future assessment of the captured volume. 3D-EUS has been used with both radial and linear transducers, especially in an attempt to improve staging of esophageal, gastric, pancreatic or rectal tumors. The aim of this clinical imaging article was to show the capabilities and perspectives of linear 3D ultrasound, including contrast-enhanced 3D-EUS. The 3D reconstruction images were acquired with a freehand technique through rotation (torque) of the EUS scope along its long axis. 3D acquisition of contrast-enhanced EUS images was also used. Esophageal, gastric and mediastinal tumors are easily visualized by 3D-EUS reconstructions and also, 3D-EUS facilitates anatomical interpretation of the images in the pancreatobiliary area. In conclusion, the advantages of 3D reconstructions in EUS are clear and multiple, especially in the assessment of the location of tumors and their relationships with neighboring organs and blood vessels.

Keywords

Endoscopic ultrasound – tridimensional (3D) – contrast-enhancement.

Introduction

Tridimensional (3D) endoscopic ultrasound (EUS) has been previously reported as an enhanced modality of displaying a sequence of bidimensional (2D) images [1-9]. Although it is considered that the method does not bring significant advantages, a better understanding of the spatial relations of the examined lesions might be possible, similar to 3D reconstructions obtained during computer tomography (CT) or magnetic resonance imaging (MRI) [9]. 3D-EUS has a better spatial resolution and allows the offline interrogation of the captured volume, able to better depict the relationship with major vessels and neighboring organs, with the aim of improving staging and assessment of resectability. The method allows accurate measurements of the volume [5, 6], being useful for treatment planning, as well as for the monitoring of tumor response during therapy [7, 8].

3D transabdominal ultrasound has been used extensively for diagnosis and image guidance, including therapy monitoring and follow-up [10]. The method uses dedicated 3D ultrasound probes, although the 3D images can be easily obtained with the usual two-dimensional probes by using freehand ultrasound reconstruction algorithms [11]. The technique has been particularly valuable for examinations in obstetrics and gynecology because it improves diagnostic efficiency in certain clinical situations related to fetal behavior or maternal-fetal bonding [12-14]. The experience obtained from 3D acquisition systems used in transabdominal ultrasound has been translated in 3D-EUS.

3D-EUS has been used both with radial and linear transducers, especially in an attempt to improve staging of esophageal, gastric, pancreatic or rectal tumors. 3D reconstructions of radial EUS can be achieved relatively easy, through linear translation of two-dimensional scans. Linear EUS is more difficult to be used for 3D reconstructions because manual angulations can induce scans from different planes, with consequent difficulties in the reconstruction of images.

The aim of this pictorial review was to show the capabilities and perspectives of state-of-the-art linear 3D ultrasound, including contrast-enhanced 3D-EUS or even 3D-EUS elastography. These techniques could allow in the future the accurate evaluation and virtual palpation of tumor volume, as well as the quantification of vascularity and follow-up during anti-angiogenic treatments.

Technical problems

Transducer guidance is difficult to obtain with a linear...
EUS scope, in order to correctly transform the bidimensional sequence of images into a tridimensional space. The simplest solution to obtain 3D images with linear EUS instruments is to freely rotate the EUS scope around its own axis, thus obtaining images that are at a constant angle between them, however situated on a sectoral disposition. This poses some problems during the 3D reconstruction especially if the images are acquired with freehand rotation techniques. Fast movements and changes in the insertion depth during axial rotation of the EUS scope might lead to artifacts or incorrect reconstructions with skipped areas. Furthermore, accurate volume calculations are not possible in the absence of electromagnetic sensors that allow position measurement (location and orientation of the transducer).

We used a Hitachi EUB 8500 ultrasound system (Hitachi Medical Corporation, Tokyo, Japan) with an embedded 3D freehand module, coupled with the EG3830 therapeutic linear array EUS scope (Pentax, Hamburg, Germany). The 3D reconstruction images were acquired with a freehand technique through rotation (torque) of the EUS scope along its long axis. The 3D display software system (EZU-3D3) was used, including separate free section and rendering displays. The free section screen displays the individual 2D images inside the 3D cube and allows the control of size, orientation, view and slice of the 3D volume. The rendering screen expresses the ultrasound image with its features enhanced with several rendering techniques available: opacity mode for gray-scale and color rendering (Fig. 1a), transparency mode for color rendering and maximum intensity projection (MIP) mode (Fig. 1b). The MIP mode assigns the maximum intensity of voxel in the projection direction, while the opacity and transparency modes display see through images.

We also used 3D acquisition of contrast-enhanced EUS images, through visualization in power Doppler mode after injection of a second generation microbubble contrast agent (Sonovue). Thus, 2.4 mL of Sonovue was injected in an antecubital vein and the region of interest was examined in real-time, by linear EUS, through the arterial phase and late venous phase. 3D contrast-enhanced power Doppler EUS images were acquired after more than 1 min. from the original injection, in the late venous phase. Transparency mode was used to display the color images in a see through manner that allowed the visualization of blood vessel structure, as well as the relationship with the tumor mass. A multiview icon display can be used to review 3D images in 4 or 6 types of views, including orthogonal views, combined orthogonal views, free-section and rendering views (Fig. 1c).

Clinical applications

Mediastinal tumors can be easily visualized by 3D-EUS, with emphasis on the relationship with the big vessels in the mediastinum (aorta and pulmonary artery). The reconstruction of 3D-images allows a better assessment of the tumor stage, as well as the relationship with the major organs and vessels in the mediastinum (Figs. 1a-c).
measurement of the tumor volume might be useful for the prediction of tumor response after chemoradiotherapy.

Esophageal and gastric tumors are easily visualized by 3D-EUS reconstructions, which help an accurate depiction of the depth of tumor invasion, usually consistent with the histological diagnosis (Figs. 2a-c) [7]. The utility of 3D-EUS has also been demonstrated for the volume measurement of early gastric cancer, because tumor volume is proven to be an independent risk factor for lymph node metastasis and consequently for prognosis in gastric cancer [6, 16].

**Fig 2a.** 3D rendering screen showing an enhanced US image in the opacity mode, delineating a T3 esophageal mass with increased collateral circulation, but also intratumoral signals visualized in the late venous phase after 2nd generation contrast-enhancement (Sonovue).

**Fig 2b.** Rendering screen of the esophageal tumor in maximum intensity projection (MIP) mode, showing an increased collateral circulation, but also intratumoral signals. Quantification of the vascular index inside the tumor mass is easily possible.

**Fig 2c.** Multiview icon display of the T3 esophageal tumor, clearly showing the distance between the tumor mass and aorta, after contrast-enhancement with Sonovue.

**Fig 3a.** A patient with advanced chronic pancreatitis with double duct sign visualized by 3D power Doppler US. A large stone (10 mm) was impacted in the proximal part of the enlarged pancreatic duct, also obstructing the common bile duct. Other small stones can be seen in the dilated pancreatic duct.

**Fig 3b.** Hypoechoic focal mass visualized during sequential slicing of the 3D cube, with suspected adenocarcinoma. The focal mass was not visible during usual 2D examinations.

**Fig 3c.** Rendering screen in transparency mode (without gray-scale information) showing a hypervascular mass in chronic pancreatitis, suggesting a benign lesion.
3D-EUS certainly facilitates anatomical interpretation of the images in the pancreatobiliary area, as well as vascular landmarks used for staging and assessment of resectability. The method might be feasible for the assessment of venous invasion and venous compression in focal pancreatic masses, in both chronic pancreatitis (Figs. 3a-c) and pancreatic cancer (Figs. 4a-c) [15]. The acquisition of 3D volume allows a retrospective assessment and slicing of the reconstructed cube, with accurate depiction of focal masses, even if missed on the initial real-time evaluation.

**Future prospects**

Contrast-enhanced power Doppler 3D-EUS can be easily performed with the 3D freehand module, yielding high quality images of the vessel structure and the relations with the tumor mass. The introduction of real-time low-mechanical index (low-MI) contrast-enhanced imaging techniques has allowed the visualization of flow signals in smaller vessels, associated with tumor neoangiogenesis [17]. Excellent 3D vascular images are now easily obtained after microbubble second generation contrast-enhancement, with a high-resolution volumetric evaluation of tumor vascularity [18]. Furthermore, quantification of the vascular index (percentage of voxels with power Doppler signal reported to the total number of voxels comprising the tumor volume) might offer important prognostic information before and during anti-angiogenic treatments.

3D EUS elastography is also available through freehand [19] or automated techniques [20], by using the usual ultrasound probes or high quality two-dimensional (2D) transducer arrays. The latter represents a promising solution for implementing real-time three-dimensional (3D) ultrasound elastography. The method might be feasible in the future for the follow-up of radio frequency ablation (RFA) lesions, which are quite difficult or impossible to be visualized through usual ultrasound methods [21]. The thermal lesions induced by RFA are not discernible in gray-scale images but they are clearly visible in the strain images, with a good agreement observed between strain (elastography) images, CT and gross pathology.

Image fusion has been used already by combining the corresponding images of real-time EUS and a pre-procedural CT or MR volume data set. The image obtained by CT or MR was acquired from the 3D volume data set through oblique reformatting and displayed simultaneously with the EUS image, side-by-side [22]. The system could be used for EUS-assisted interventions, including EUS-FNA biopsy sampling.

In conclusion, the advantage of 3D reconstructions in EUS seems to appreciate the exact location of tumors and their relationships with neighboring organs and vessels. This is especially helpful to improve staging and resectability, through a better assessment of depth of invasion in infiltrating lesions. Accurate volume measurements, as well as quantification of intratumoral vascularisation, are also important for the follow-up of patients during therapy. However, further progress of the technology is still necessary in order to obtain automatic acquisition algorithms and data corresponding to the CT or MR volume reconstructions. Application of 3D techniques in EUS or laparoscopic ultrasound (LUS) might open a door for complex NOTES procedures, by obtaining accurate information on anatomical landmarks.
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References