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● *Original Contribution*

ASSESSING THE IMAGING CAPABILITIES OF RADIAL MECHANICAL AND ELECTRONIC ECHO-ENDOSCOPES USING THE RESOLUTION INTEGRAL

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Abstract—Over the past decade there have been significant advances in endoscopic ultrasound (EUS) technology. Although there is an expectation that new technology will deliver improved image quality, there are few methods or phantoms available for assessing the capabilities of mechanical and electronic EUS systems. The aim of this study was to investigate the possibility of assessing the imaging capability of available EUS technologies using measurements of the resolution integral made with an Edinburgh Pipe Phantom. Various radial EUS echo-endoscopes and probes were assessed using an Edinburgh Pipe Phantom. Measurements of the resolution integral (*R*), depth of field (L_R) and characteristic resolution (D_R) were made at all operating frequencies. The mean *R* value for Fuji miniprobes was 16.0. The GF-UM20 and GF-UM2000 mechanical radial scopes had mean *R* values of 24.0 and 28.5, respectively. The two electronic radial echo-endoscopes had similar mean *R* values of 34.3 and 34.6 for the Olympus GF-UE260 and Fujinon EG-530 UR scopes, respectively. Despite being older technology, the mechanical GF-UM2000 scope had superior characteristic resolution (D_R), but could not compare with the depths of field (L_R) delivered by the current generation of electronic radial scopes, especially at the standard operating frequencies of 7.5 and 12 MHz. (E-mail: S.inglis@ed.ac.uk)

Key Words: **Radial, Endoscopic ultrasound, Resolution integral, Edinburgh Pipe Phantom.**

INTRODUCTION

Endoscopic ultrasound (EUS) is a well-established technique for the investigation of malignant and benign gastro-intestinal (GI) disorders. The primary use of radial EUS is in the staging of upper GI cancers, using the TNM Classification of Malignant Tumors (Sobin et al. 2009). T1 describes early-stage tumors, and T4, advanced-stage tumors. N staging ranges from N0 to N4, depending on the presence, size and number of local nodes involved. M stages indicate the presence of metastatic invasion. Clinically, the ideal EUS system should be able to, in the esophagus and stomach, resolve five to seven layers within a GI wall 2 to 5 mm thick, within 1 cm of the transducer face, and image surrounding anatomy up to 5 cm in depth to detect tumor invasion and regional lymphadenopathy. This requires that the EUS equipment have good axial and lateral resolution. Good axial resolution at user selectable operational frequencies between 5 and 20 MHz is usually achievable (Fig. 1a). However, accurate examination of deep structures to identify subtle changes in the wall of the organ under investigation depends on adequate lateral resolution. This is most important in EUS tumor staging (T staging), where tumor invasion into the layers of the GI tract wall may be small enough to be masked by poor lateral resolution. This may be a result of a poorly focused beam, large element size in electronic transducers or an improperly driven scanner. In Figure 1b and c are examples of two borderline T2/T3 esophageal tumors with suspected small breaks in the muscularis propria imaged by two different echo-endoscopes. Figure 1b illustrates that the mechanical EUS system was able to achieve good lateral resolution, leaving little doubt regarding a suspected break/infiltration of the layer under investigation; in contrast, the electronic EUS system could be challenged as to the clarity of imaging such breaks.

In the context of pancreatobiliary pathology, an EUS system should be able to resolve gallstones as small as 2 mm within a depth range of 20 to 30 mm and detect pancreatic lesions as small as 5 mm to a depth of 5 cm.

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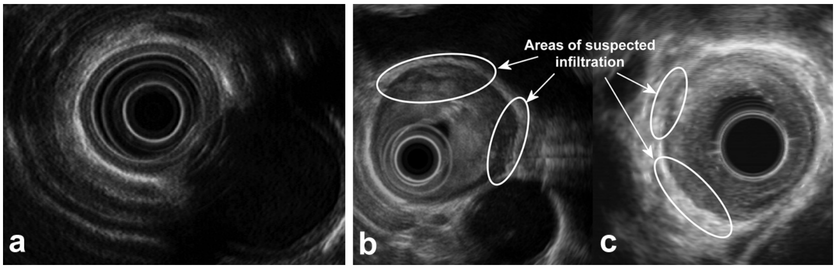

Fig. 1. (a) Images of normal esophageal wall layers acquired at 12 MHz using the mechanical GF-UM2000 echo-endoscope (seven layers are visible). (b, c) The importance of lateral resolution is illustrated by these examples of borderline T2/T3 tumors with suspected small breaks in the final wall of the esophagus captured using (b) the GF-UM2000 echo-endoscope and EU-M2000 processor at 7.5 MHz and an image display diameter of 9 cm and (c) the GF-UE260 echo-endoscope and Aloka α5 using tissue harmonics (*i.e.*, harmonics of 5 MHz fundamental) and an image display diameter of 6 cm.

Gastro-intestinal ultrasound endoscopes can be categorized by transducer type. At present there are two different types of transducer: radial and curvilinear. The radial transducer has a 360° field of view, perpendicular to the insertion tube, and is used predominately for diagnostic scanning. The curvilinear has a 120° to 180° scanning field of view, in line with the insertion tube, and is used for therapeutic procedures. Radial EUS echo-endoscopes use both mechanical and electronic technologies to produce the ultrasound image. Mechanical transducers incorporate a mechanically driven rotating single-element piezoelectric element mounted at the tip of the endoscope, within an oil-filled housing (Tio 1988; Tio et al. 1989). However, one disadvantage of this design is that the housing introduces ringdown artifacts that can mask superficial structures. As transducer array manufacturing advanced, it became possible to manufacture 360° radial solid-state electronic arrays capable of being fitted to endoscopes. These transducers can have 64 or more elements (Dan et al. 2011; Wakabayashi et al. 2007), and a previous 270° echo-endoscope developed by Hitachi-Pentax (Hitachi Medical, Tokyo, Japan) was reported to have 192 elements (Niwa et al. 2004). The development of tightly curved solid-state transducer arrays eliminates the need for an oil-filled plastic housing and associated artifacts. With radial and curvilinear EUS endoscopes, acoustic contact with the wall of the GI tract is still obtained by using a water-filled balloon (Yusuf et al. 2007). At present the purchase of endoscopic ultrasound equipment is based solely on the endoscopist's opinion after a short period of evaluation of the system on patients. This can be biased by the subjective preferences of the individual endoscopist, variations in the detailed pathology of individual patients and differences in the anatomic areas selected for the scan (esophagogastric or pancreatobiliary). Over the years, a number of studies have been performed comparing mechanical and electronic radial echo-endoscopes (Hikichi et al. 2010; Niwa et al. 2004; Ogawa et al. 2006; Papanikolaou et al. 2009; Yasuda et al. 2004), and all conclude that electronic echo-endoscopes have image quality similar to or better than that of mechanical echo-endoscopes. However, these were typically clinical evaluations of each type of echo-endoscope used on different patients, and employed subjective criteria for the assessment the image quality.

A number of commercial ultrasound quality assurance (QA) phantoms are available for performance testing of diagnostic ultrasound equipment. These are used predominately to test axial resolution, lateral resolution, uniformity, dead zones, depth of visualization, high- and low-contrast imaging and spatial calibration of callipers (Russell 2010). However, only a few ultrasound phantoms are suitable for performance testing of EUS or other radial transducer equipment. These phantoms are commonly used for specialist application training (*e.g.*, seed placement in brachytherapy, prostate biopsy). A significant problem arises during QA, equipment evaluation or assessment of phantom performance. The wide range of operating frequencies available with EUS equipment (5–25 MHz) complicates the selection or design of suitable phantoms, as the properties (*e.g.*, attenuation, speed of sound) of most commercial tissue-mimicking materials (TMMs) are stated for a single or limited range of frequencies, but not over such a wide range of frequencies. The only purpose-built phantoms that can be used with EUS and similar equipment are the Model 570 Multipurpose Endoscopic Phantom (ATS Laboratories, Bridgeport, CT, USA) and the Model 045 Brachytherapy QA phantom (CIRS, Norfolk, VA, USA). The ATS phantom is constructed from urethane rubber; however, Browne et al. (2003) found that the attenuation can vary significantly between 2.25 MHz (0.43 dB/cm/MHz) and 15 MHz (2.53 dB/cm/MHz). The CIRS phantom is manufactured from Zerdine, a water-based polyacrylamide gel formulated to match the acoustic properties of soft tissues (Hungr et al. 2012). Acoustic measurements by Browne et al. (2003) indicated that Zerdine