Utility of 3-dimensional image reconstruction in the diagnosis of small-bowel masses in capsule endoscopy (with video)

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Background: In small-bowel capsule endoscopy (SBCE), differentiating masses (ie, lesions of higher probability for neoplasia) requiring more aggressive intervention from bulges (essentially, false-positive findings) is a challenging task; recently, software that enables 3-dimensional (3D) reconstruction has become available.

Objective: To evaluate whether "coupling" 3D reconstructed video clips with the standard 2-dimensional (s2D) counterparts helps in distinguishing masses from bulges.

Design: Three expert and 3 novice SBCE readers, blind to others and in a random order, reviewed the s2D video clips and subsequently the s2D clips coupled with their 3D reconstruction (2D+3D).

Setting: Multicenter study in 3 community hospitals in Italy and a university hospital in Scotland.

Patients: Thirty-two deidentified 5-minute video clips, containing mucosal bulging (19) or masses (13).

Intervention: 3D reconstruction of s2D SBCE video clips.

Main Outcome Measure: Differentiation of masses from bulges with s2D and 2D+3D video clips, estimated by the area under the receiver operating characteristic curve (AUC); interobserver agreement.

Results: AUC for experts and novices for s2D video clips was .74 and .5, respectively ($P = .0053$). AUC for experts and novices with 2D+3D was .70 (compared with s2D: $P = .245$) and .57 (compared s2D: $P = .049$), respectively. AUC for experts and novices with 2D+3D was similar ($P = .1846$). The interobserver agreement was good for both experts and novices with the s2D ($k = .71$ and .54, respectively) and the 2D+3D video clips ($k = .58$ in both groups).

Limitations: Few, short video clips; fixed angle of 3D reconstruction.

Conclusions: The adjunction of a 3D reconstruction to the s2D video reading platform does not improve the performance of expert SBCE readers, although it significantly increases the performance of novices in distinguishing masses from bulging. (Gastrointest Endosc 2014;80:642-51.)

Abbreviations: 2D, 2-dimensional; 3D, 3-dimensional; AUC, area under the (ROC) curve; CE, capsule endoscopy; MB, mucosal bulge; ROC, receiver operating characteristic; s2D, standard 2D; SBCE, small-bowel capsule endoscopy.

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Since its introduction in clinical practice in 2001, small-bowel capsule endoscopy (SBCE) has become a prime mode for the evaluation of the small bowel in several clinical settings, such as obscure GI bleeding and Crohn's disease.[1] In this context, SBCE has a high yield of findings and a positive impact on diagnosis and patient management (ie, cost-effectiveness).[2,3] The most common small-bowel findings (ie, angioectasias, ulcers, and/or luminal stenosis) are easy to recognize and are rarely missed.[4] Conversely, large small-bowel protruding lesions (eg, small-bowel mass lesions) can be missed by capsule endoscopy (CE), and the value of a negative SBCE in excluding sinister small-bowel pathology remains unclear.[5-9] Furthermore, those of us who routinely read SBCE studies can attest that luminal protrusions in SBCE are a common finding.

The presence of a "mass" can be the result of several processes, for example, mucosal disruption by underlying pathology, a lesion with intact overlying intact mucosa (either because of submucosal or extramural/extrinsic origin), and/or a false-positive finding from bowel contraction, loop angulation, or even intussusception.[10,11] Luminal protrusions with changes in color (erythema) and signs of mucosal disruption (exudates, erosions, and ulcers) are highly suggestive of a neoplastic process; however, in most cases the CE appearance of masses (ie, clinically significant lesions of higher probability for neoplasia) is not dissimilar to that of innocent mucosal bulges (MBs). MBs are defined as round, smooth, large-based luminal protrusions with ill-defined boundaries, resulting either from loop angulations and/or impression from adjacent loops/structures.[10] They are benign endoscopic findings of no clinical significance, essentially false-positive findings.[1,12] Furthermore, a small-bowel lesion can be depicted only in few frames and/or a mass may only be seen tangentially, and it cannot be sampled or probed.[1,12] Therefore, an accurate distinction between masses and MBs is crucial, because missing a tumor can eventually jeopardize a curative resection and patient prognosis. On the other hand, misclassifying an innocent small-bowel MB as a neoplastic mass may lead to unnecessary, invasive, and—most of the time—expensive procedures. Girelli and Porta[10] noted that a smooth, round, protruding "mass" exhibits the following characteristics when it is associated with the innocent MB: (1) an ill-defined boundary with the surrounding mucosa, (2) a diameter larger than its height, (3) no visible lumen in the frames in which it appears, and (4) an image lasting less than 10 minutes.[10,12]

Software tools (eg, flexible spectral imaging color enhancement, Blue mode, and/or suspected blood indicator) have been developed to assist capsule reviewers with so-called difficult to characterize small-bowel lesions.[13] Research has been carried out to produce 3-dimensional (3D) reconstruction of the GI tract using stereoscopic vision methods.[14] However, because of technologic limitations inherit to SBCE (ie, packaging in capsule-size endoscopes and power consumption constraints),[15] hardware-enabled 3D reconstruction of the intestinal lumen is yet to be available.[16] Over the last few years, software that enables 3D representation/approximation (Shape-from-Shading) from monocular 2-dimensional (2D) SBCE images has been developed.[17] This software recovers the shape of objects from 2D images using gradual variation of shading.[18] Recently, we showed that application of such software in SBCE leads to image enhancement for a significant proportion of vascular and protruding small-bowel lesions.[19] However, to the best of our knowledge, this reconstruction has been applied only to still images (not to video segments); furthermore, most studies performed thus far focused more on technical aspects (ie, quality of images/visualization)[19-21] than on clinical issues (ie, reaching a diagnosis).[22]

In this 2-phase study we aimed to evaluate whether coupling the standard 2D (s2D) video clips with a 3D reconstruction enhanced the performance of SBCE readers (with different level of SBCE experience) in distinguishing masses from innocent MB.

Take-home Message

- The distinction between masses and innocent mucosal bulging at small-bowel capsule endoscopy (SBCE) is a difficult task even for experienced readers. The adjunction of a 3D reconstruction software to the standard capsule endoscopy (CE) 2D view significantly improves the performance of novice readers in distinguish between masses and bulging.
- The use of a 3D reconstruction software could be useful in the training of novice CE readers.

METHODS

Phase 1: choosing the optimal angle for 3D video reconstruction

PillCam SB2 (Given Imaging Ltd, Yoqneam, Israel) captures two 2D frames per second. These images are displayed in sequence, as the relevant proprietary software (RAPID; Given Imaging Ltd, Yoqneam, Israel) generates a video that gives the impression of movement of the capsule through the small bowel. To re-create 3D video clips for the purpose of this study, short 2D video segments were selected and broken down into the frames that constituted them. Individual frames were 3D reconstructed and recompressed to respective 3D videos. For this task, dedicated 3D visualization software was developed in a Mathworks Matlab (MathWorks Inc, Natick, Mass, USA) environment. It should be noted that when a single image is reconstructed in 3D, the user can manipulate the viewing angle and rotate at 360 degrees and zoom in or out, whereas there is no freedom to rotate the viewing angle of all the 3D images stitched together in a 3D video. For this reason, before proceeding with the main evaluation, it was necessary to decide the optimal