Surgical Endoscopy (2019) 33:4164–4170
https://doi.org/10.1007/s00464-019-06726-w

Comparison of 3D endoscopy and conventional 2D endoscopy in gastric endoscopic submucosal dissection: an ex vivo animal study

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Received: 5 May 2018 / Accepted: 1 March 2019 / Published online: 6 March 2019

Abstract

Background and objectives Conventional endoscopy provides two-dimensional (2D) information without depth information. This study compared three-dimensional (3D) endoscopy and 2D endoscopy using an endoscopic submucosal dissection (ESD) training model to evaluate the utility of 3D endoscopy.

Methods Porcine stomach specimens (7 × 7 cm) were prepared from commercially available resected porcine stomachs and a 10-mm hypothetical lesion was marked at the center of each specimen. Specimens were individually placed in an ESD training model, and subjected to either 2D or 3D ESD. En bloc resection rate, perforation rate, incision time, dissection time, and levels of five eyestrain symptoms (fatigue, pain, blurred vision, head-heaviness, and headache; 100-mm visual analog scale) were compared between the 2D and 3D procedures. In a crossover design, 8 endoscopists each performed two 2D and two 3D procedures.

Results All 32 lesions were resected en block, but perforation occurred in one 2D procedure. Incision time was significantly shorter in 3D ESD than in 2D ESD (102.8 ± 42.1 s vs. 135.8 ± 65.7 s, $p < 0.05$). Dissection time was also significantly shorter in 3D ESD than in 2D ESD (366.3 ± 187.6 s vs. 517.8 ± 282.3 s, $p < 0.05$). Differences in levels of all symptoms except blurred vision between before and after ESD were larger in 3D ESD than in 2D ESD.

Conclusions Incision time and dissection time were significantly shorter in 3D ESD compared with 2D ESD, but eyestrain was increased. Depth information from 3D images appears to facilitate rapid and stable ESD maneuvers.

Keywords Three-dimensional imaging (3D) · 3D endoscope · Endoscopic submucosal dissection (ESD) · Porcine stomach · Eyestrain

Introduction

Conventional endoscopy provides two-dimensional (2D) information only, and thus depth information is not available. Endoscopic treatment relies on the information displayed on the monitor, but currently available 2D images provide little spatial information, so endoscopists must rely on their own experience. Rigid 3D endoscopy was recently introduced in clinical surgery, and its use and utility have been reported in several studies [1–3]. However, development of a flexible 3D endoscope for gastrointestinal examination and treatment has been delayed due to structural differences; this was eventually achieved by Olympus Corp., and the diagnostic and therapeutic benefits were reported by our group [4–6].

We conducted an ex vivo animal study using an ESD training model with porcine resected stomachs to investigate whether 3D endoscopy is more useful than 2D endoscopy in ESD. We also examined whether trainees and experts prefer 2D or 3D systems.

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Materials and methods

Endoscopic imaging and observation

The dimensions of the newly developed 3D prototype endoscope (GIF-Y0083; Fig. 1a, b) were outer diameter at the tip of the scope, 12.2 mm; maximum diameter of the scope, 14.1 mm; length of the scope, 1030 mm; and the diameter of the channel, 2.8 mm. Although magnification is not feasible, the endoscope is equipped with narrow-band imaging and water jet technologies. This newly developed 3D prototype endoscope was used along with an endoscopic system identical to that used in surgery: EVIS EXERA III Video System Center, 3D Visualization Unit (CV-190), and EVIS EXERA III Xenon Light Source (3DV-190), and EVIS EXERA III (CLV-190) (all from Olympus) as well as 3D Medical Display (LMD-3251MT; Sony). Images are obtained through each lens and sent to each video processor as an electrical signal. Each video processor changes the electrical signal to video signal similar to the working of the conventional endoscope. Each video signal is send to a 3D video processor and synthesized as a 3D image. Finally, 3D image is visualized using 3D monitor and 3D glasses [6]. In these systems, 2D mode can be switched to 3D mode and vice versa with one button.

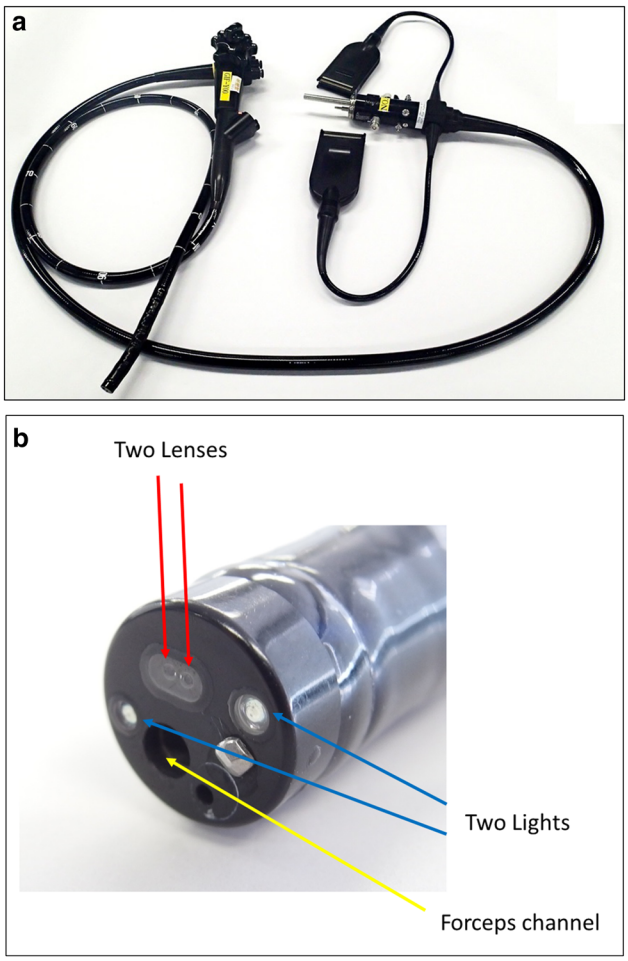

Fig. 1 **a** The newly developed 3D prototype endoscope (Olympus, GIF-Y0083). **b** The image of the tip of 3D flexible endoscope. There are 2 lenses at the tip of the endoscope (red arrow). (Color figure online)

Study design

Eight endoscopists participated in this study. Each endoscopist performed two 2D ESD procedures and two 3D ESD procedures (32 procedures in total); en bloc resection rate, perforation rate, incision time, dissection time, and eyestrain level were compared between the 2D procedures and 3D procedures. Participants were divided into trainees who had performed 5–50 ESD procedures and experts who had performed 100 or more ESD procedures. A crossover design was used to minimize bias related to familiarity with the procedures. One-half of the trainees and experts were allocated to the 2D-first group and the other half to the 3D-first group. In the corresponding group, 2D ESD or 3D ESD was performed first followed by the other procedure. Then, after a washout period of at least 2 weeks, a second set of two procedures was performed in the reverse order (Fig. 2). The ethics committee of our hospital approved this study (approval no. 29-1).

Endoscopic submucosal dissection

Porcine stomach specimens (7 × 7 cm) were prepared from commercially available resected stomachs. A 10-mm hypothetical lesion was drawn at the center (Fig. 3a), and each specimen was placed onto the fixation plate, which was then fixed to the ESD training model (LM-083; Koken Co.

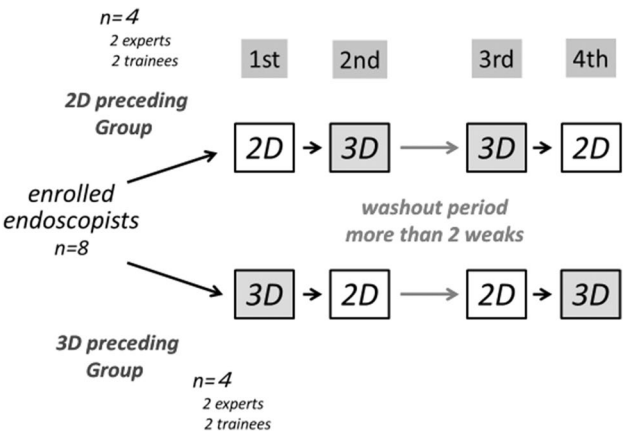

Fig. 2 Flow diagram of the study

Fig. 3 **a** A 10-mm mark drawn at the center of each specimen prepared from resected porcine stomach. **b** ESD training model (LM-083, Koken Co. Ltd.). **c** Counter electrode plate bonded to the fixation plate

Ltd., Tokyo, Japan) with fixation belts (Fig. 3b). A counter electrode plate was then bonded tightly to the specimen (Fig. 3c). The ESD procedure was performed with a dual knife (KD-650Q; Olympus Medical Science, Tokyo, Japan). A 10% glycerin solution (Glyceol, Chugai Pharmaceutical Co., Tokyo, Japan) was injected into the area around the hypothetical lesion and a circumferential incision was made with the dual knife. Next, the submucosa was dissected under direct visualization and the lesion was resected. All hypothetical lesions were on the lesser curvature of the lower body of the stomach (Fig. 4a, b). In this study, a training model was selected in which ESD was performed to remove a hypothetical lesion on a piece of porcine stomach, not a lesion in the whole resected stomach. This choice was made so that differences in operability attributable to the location of the lesion could be eliminated and all ESD procedures could be performed under nearly identical conditions. The lesser curvature of the lower body of the stomach was chosen as the location of the hypothetical lesion because it offers the best operability compared to the other locations that can be used in this training model.

Evaluation of subjective eyestrain symptoms using a visual analog scale questionnaire

The levels of five subjective symptoms of eyestrain (fatigue, pain, blurred vision, head-heaviness, and headache) were determined using a 100-mm visual analog scale (VAS), on which participants marked the level of each symptom. The 0 (base) and 100-mm points indicated no symptom and the maximum/worst condition, respectively; with graduations of 0.5 mm from the base to the marked point. Mean values for individual participants before and after ESD were obtained.

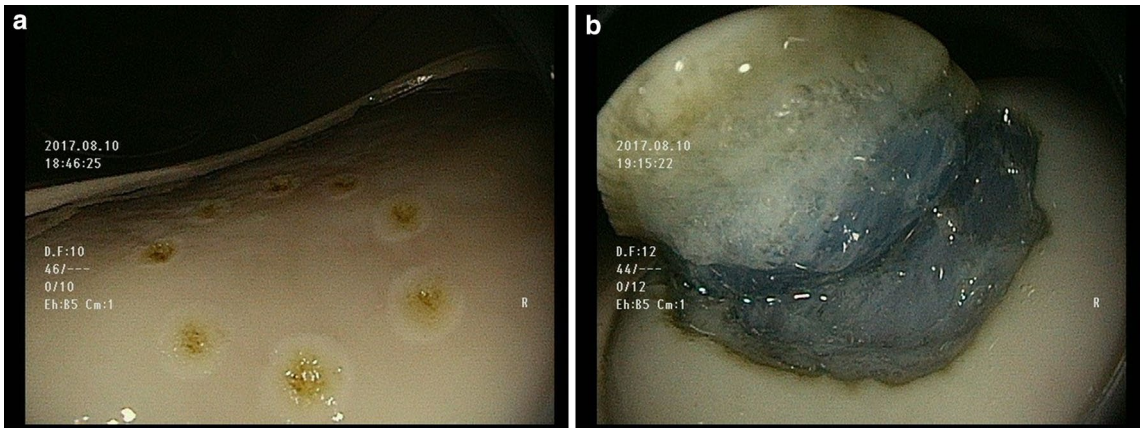

Fig. 4 **a** Confirmation of the 10-mm mark (2D image). **b** Submucosal dissection of the anal side of the lesion (2D image)

Table 1 Treatment outcomes

	2D	3D	p
Number	16	16	
En block resection [*n* (%)]	16 (100%)	16 (100%)	
Perforation [*n* (%)]	1 (6.25%)	0 (0%)	0.31
Incision time (s)	135.8 ± 65.7	102.8 ± 42.1	< 0.05
Dissection time (s)	517.8 ± 282.3	372.6 ± 185.0	< 0.05

Table 2 Treatment outcomes by skill level

	2D	3D	p
Trainee			
En block resection [*n* (%)]	8 (100%)	8 (100%)	
Perforation [*n* (%)]	1 (12.5%)	0 (0%)	0.30
Incision time (s)	159.5 ± 60.9	116.9 ± 42.6	< 0.01
Dissection time (s)	652.8 ± 329.0	432.9 ± 195.8	< 0.05
Expert			
En block resection [*n* (%)]	8 (100)	8 (100)	
Perforation [*n* (%)]	0 (0%)	0 (0%)	
Incision time (s)	112.0 ± 61.6	88.8 ± 36.6	0.192
Dissection time (s)	382.9 ± 121.6	312.3 ± 151.0	< 0.05

Statistical analysis

Data are presented as mean ± standard deviation. Statistical analysis was performed using the χ^2 test and paired *t* test. All statistical analyses were performed using Stata version 14 (StataCorp, College Station, TX, USA) and p value of < 0.05 was considered to be statistically significant.

Results

Treatment outcomes

All 32 lesions were resected en block, but perforation occurred in one 2D ESD procedure performed by a trainee. Time required to make a circumferential incision was significantly shorter in 3D ESD than in 2D ESD (102.8 ± 42.1 s vs. 135.8 ± 65.7 s, $p < 0.05$). Dissection time was also significantly shorter in 3D ESD than in 2D ESD (366.3 ± 187.6 s vs. 517.8 ± 282.3 s, $p < 0.05$) (Table 1). Among trainees, both circumferential incision time and dissection time were significantly shorter in 3D ESD than in 2D ESD ($p < 0.05$). In contrast, there was no difference in the circumferential incision time among experts, but dissection time was significantly shorter in 3D ESD than in 2D ESD (312.3 ± 151.0 s vs. 382.3 ± 121.6 s, $p < 0.05$) (Table 2).

Eyestrain

VAS measurements are shown in Table 3. Levels of all eyestrain symptoms, except head-heaviness, were higher after 2D ESD than before, while levels of all symptoms were higher after 3D ESD than before (Table 3). Levels of ESD-induced eyestrain (pre- vs. postoperative) were more severe in 3D ESD than in 2D ESD for the symptoms of fatigue, pain, head-heaviness, and headache but not for blurred vision (Table 4).

Discussion

The resolution of endoscopic images has been increasing in recent years, while 3D visualization remains an unresolved challenge. Experienced endoscopists use their experience to construct predictive 3D structures from 2D information displayed on the monitor during endoscopic procedures. However, such empirical prediction differs from actual 3D structure, and thus cannot provide complete sets of spatial

Table 3 Evaluation of subjective eyestrain symptoms using a VAS questionnaire

	2D		3D	
	Before ESD	After ESD	Before ESD	After ESD
Eye fatigue	2.90 ± 2.23	4.09 ± 2.11**	3.19 ± 2.32	5.13 ± 2.41**
Eye pain	1.81 ± 1.81	2.27 ± 2.08 *	1.81 ± 1.64	3.34 ± 2.78**
Blurred vision	1.88 ± 2.23	2.63 ± 2.55*	2.44 ± 2.40	3.56 ± 2.55**
Heaviness in head	1.84 ± 1.38	2.03 ± 1.44	1.94 ± 1.59	3.38 ± 2.39**
Headache	1.56 ± 1.30	1.84 ± 1.33*	1.63 ± 1.33	2.63 ± 2.09**

*Significant difference between before and after ESD: $p < 0.05$

**Significant difference between before and after ESD: $p < 0.01$

Table 4 Differences in eyestrain levels before and after ESD

	2D	3D	p
Eye fatigue	1.19 ± 0.88	1.94 ± 0.88	< 0.05
Eye pain	0.45 ± 0.78	1.53 ± 1.50	< 0.05
Blurred vision	0.75 ± 0.79	1.13 ± 1.07	0.097
Heaviness in head	0.19 ± 0.53	1.44 ± 1.73	< 0.05
Headache	0.28 ± 0.61	1.00 ± 1.30	< 0.05

information about the tissue. This may result in misjudging tissue conditions, possibly causing unintended damage to tissue and unwarranted bleeding. Conversely, 3D endoscopy provides true 3D information, and thus will improve the safety of procedures.

Individuals with normally developed brain function have stereoscopic vision, which is the perception of 3D structure and depth converted from the disparity between the distinct views derived from the eyes. Three-dimensional visualization requires special lenses to provide a perception of depth based on images taken with two cameras displayed on the same monitor. Three-dimensional images are widely available today, often in movies and theme park attractions. Today, 3D visualization is steadily spreading in medical and health care fields, particularly in the field of surgery. It is difficult to perceive spatial positions of organs and the surgical field depth with only 2D information as is available with conventional endoscopic surgery. Three-dimensional endoscopy overcomes this problem, and its utility and safety have been reported in many studies [7–12]. With newly added depth information, 3D endoscopy will be useful in diagnosis; we have reported the utility of a newly developed flexible 3D endoscopy in recognizing lesions and performing procedures [5, 6]. This study investigated the utility of flexible 3D endoscopy in ESD. Although we used a training model, this is the first direct crossover comparison of the utility of 3D and 2D endoscopy in endoscopic treatment.

This study showed that use of a 3D endoscope significantly reduced both incision time and dissection time, probably because the procedures were performed with depth information provided by the 3D endoscope. Comparing within skill level-based subgroups, incision time was significantly reduced among trainees, but not among experts. When placing a circumferential incision with a 2D endoscope, trainees did not insert the device deep enough, so, repeated insertions (twice or thrice) were required at the same site. However, the depth information was available with a 3D endoscope, and this apparently enabled the endoscopists to make an appropriate incision at the sufficient depth. It is rare for experts to make several incisions at the same position, so this may be the reason for no difference in incision time between 2D and 3D procedures among experts. Nonetheless, use of a 3D endoscope reduced dissection time among both trainees and experts. It is likely that 3D information enables both experts and trainees to clearly recognize the position of the edge of the device and the distance to the muscular layer, and to precisely place the edge of the device at the submucosal layer, thereby achieving effective dissection in reduced time.

We did not test enough procedures to prove the safety of 3D ESD in this study, but the addition of depth information will surely improve safety. To improve the accuracy and safety of procedures, 3D information is crucial for trainees with as yet insufficient experience. Also, as an assistant, a trainee can share 3D information acquired during endoscopic treatment conducted by an expert endoscopist, and this will help trainees learn and improve their skills, thereby reducing the required time for acquiring endoscopic skills. It is noteworthy that 3D endoscopy is beneficial in treatment even among experts, suggesting that 3D endoscopy may contribute to new innovations in gastrointestinal endoscopic treatment.

The major challenge with 3D procedures is eyestrain [13]. Increased eyestrain from persistent observation of 3D images has been reported in several studies [14–17], and could possibly be explained by the discrepancy between accommodation and convergence caused by perception of stereoscopic images derived from artificially induced binocular parallax [18]. This study confirmed significantly worse eyestrain in 3D ESD than in 2D ESD, although a certain level of eyestrain was caused by 2D ESD as well.

Eyestrain may be alleviated as endoscopists get used to 3D procedures, but this point needs to be addressed by future innovations in 3D endoscopy technology.

Resolution of 3D endoscopic images is slightly lower than that of images available with a full high-definition 2D endoscope. Also, a 3D endoscope is usually slightly thicker than a conventional 2D endoscope, and 3D endoscopes do not have multi-bending function. These are considerable disadvantages in clinical application, and future improvements are awaited.

There are a few limitations to this study. First, this is not an in vivo animal model, but an ex vivo study using resected porcine stomachs. Secondly, the sample size of 8 endoscopists (32 procedures) is too small to assure an adequate detection power. Thirdly, the endoscopist could not be blinded to the type of ESD (2D or 3D ESD), and this could produce a bias. Further, management of bleeding, which is critical in clinical cases, was not assessed because our training model used resected porcine stomachs. Advantages of 3D endoscopy in management of bleeding are easier visual confirmation of the bleeding site and consequently more accurate placement of the device at the target position. On the other hand, the dual camera system enabling reconstruction of 3D images does not function if one lens is submerged in a pool of blood when bleeding occurs. This is a disadvantage of 3D endoscopy. A prospective study using a large number of clinical subjects is awaited in which the management of bleeding can also be assessed. Further, comparison of our 3D system with endoscopes widely used in the clinical setting (e.g., Olympus GIF-Q260J and GIF-2TQ260) in ESD is necessary to confirm its clinical utility.

Following approval, clinical studies of 3D endoscopy have commenced and its utility in screening and in treatment is currently being investigated.

In conclusion, using a training model, this study showed that 3D ESD significantly reduced incision time and dissection time compared with 2D ESD. The reduction was significant among experts, as well as among trainees. Depth information available with a 3D endoscope likely enables more rapid and stable performance of ESD. Future clinical use is anticipated.

Compliance with ethical standards

Disclosures Kosuke Nomura, Daisuke Kikuchi, Mitsuru Kaise, Toshiro Iizuka, Yorinari Ochiai, Yugo Suzuki, Yumiko Fukuma, Masami Tanaka, Yosuke Okamoto, Satoshi Yamashita1, Akira Matsui, Toshifumi Mitani, and Shu Hoteya have no conflict of interest or financial ties to disclose.

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