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Diagnostic performance of endoscopic ultrasound-artificial intelligence using deep learning analysis of gallbladder polypoid lesions

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Key words

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Abstract

Background and Aim: Endoscopic ultrasound (EUS) is the most accurate diagnostic modality for polypoid lesions of the gallbladder (GB), but is limited by subjective interpretation. Deep learning-based artificial intelligence (AI) algorithms are under development. We evaluated the diagnostic performance of AI in differentiating polypoid lesions using EUS images.

Methods: The diagnostic performance of the EUS-AI system with ResNet50 architecture was evaluated via three processes: training, internal validation, and testing using an AI development cohort of 1039 EUS images (836 GB polyps and 203 gallstones). The diagnostic performance was verified using an external validation cohort of 83 patients and compared with the performance of EUS endoscopists.

Results: In the AI development cohort, we developed an EUS-AI algorithm and evaluated the diagnostic performance of the EUS-AI including sensitivity, specificity, positive predictive value, negative predictive value, and accuracy. For the differential diagnosis of neoplastic and non-neoplastic GB polyps, these values for EUS-AI were 57.9%, 96.5%, 77.8%, 91.6%, and 89.8%, respectively. In the external validation cohort, we compared diagnostic performances between EUS-AI and endoscopists. For the differential diagnosis of neoplastic and non-neoplastic GB polyps, the sensitivity and specificity were 33.3% and 96.1% for EUS-AI; they were 74.2% and 44.9%, respectively, for the endoscopists. Besides, the accuracy of the EUS-AI was between the accuracies of mid-level (66.7%) and expert EUS endoscopists (77.5%).

Conclusions: This newly developed EUS-AI system showed favorable performance for the diagnosis of neoplastic GB polyps, with a performance comparable to that of EUS endoscopists.

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Introduction

Polypoid lesions of the gallbladder (GB) are abnormal elevated lesions of the GB mucosal wall into the GB lumen and encompass a wide variety of pathologies. They can be classified into non-neoplastic (cholesterol polyps, inflammatory polyps, and adenomyomatosis) or neoplastic types (adenoma and adenocarcinoma),¹ as well as benign or malignant (adenocarcinoma). Although the widespread use of ultrasonography (US) has improved detection of a variety of GB diseases, differential diagnosis of GB polyps, particularly small lesions (≤ 20 mm in diameter), is difficult because GB lesions cannot be biopsied.²

Currently, endoscopic ultrasound (EUS) is considered superior to conventional US in terms of GB examination. EUS uses a high-frequency transducer to observe GB polyps at high resolution, which can improve the discrimination of neoplastic GB polyps and aid in staging of GB cancers.³ In addition, it is useful to differentiate neoplastic and non-neoplastic GB polyps based on the presence of typical EUS features, such as hypoechoic foci, hyperechoic spot, microcyst, and Doppler flow, as well as complex scoring systems.^{2,4,5} Contrast enhanced harmonic EUS can discriminate between adenomatous and cholesterol GB polyps based on enhancement patterns,⁶ and increase the sensitivity in identification of malignant GB polyps.⁷ However, the interpretation of EUS and contrast enhanced harmonic-EUS images by visual assessments is subjective; therefore, an objective analysis technique for discriminating GB diseases is required. Artificial intelligence (AI) is a mathematical prediction technique involving automated learning and recognition data patterns. Deep learning is an AI algorithm and an advanced type of machine learning method that uses neural networks.⁸ Remarkable advancements have recently been made in increasing the efficacy of AI and decreasing the cost associated with diagnosis of various gastrointestinal lesions.^{9,10} However, no studies have used AI to differentiate among various GB polyps. Thus, we evaluated the diagnostic performance of AI for differentiating GB polyps using EUS images.

Methods

Patients. Preoperative EUS images of pathologically confirmed GB polyps and gallstones were retrospectively collected between January 2014 and May 2019 as the AI development cohort. All EUS examinations were performed with a real-time, gray-scale sector scan echoendoscope EUS (GF-UCT260 or GF-UE260-AL5; Olympus, EG3870UTK; Pentax, Tokyo, Japan) by well-trained endoscopists at the EUS unit of Gachon University Gil Medical Center and Yonsei University College of Medicine, Gangnam Severance Hospital. The diagnostic accuracy of EUS-AI may vary depending on the quality of the training EUS images. To account for this, an expert endoscopist viewed all EUS images obtained by endoscopists with at least an intermediate level of experience and selected the optimal training images.

The inclusion criterion was the presence of GB polyps with maximum diameter of 7–20 mm. Multiple images from a single patient were selected from different lesions. The AI development cohort consisted of 1039 EUS images of GB lesions (836 GB polyps and 203 gallstones) from 670 patients who underwent cholecystectomy. An external validation cohort was created with 83 EUS images from 83 patients who underwent preoperative EUS

and cholecystectomy between June 2019 and January 2020, which allowed additional verification of the EUS-AI algorithm. EUS images collected from each hospital for external validation were evaluated by endoscopists from other hospitals; the endoscopists were blinded to the clinical data. The diagnostic performance of GB polyps using the EUS-AI system was compared with the diagnostic performances of seven EUS endoscopists; interobserver agreement was determined between the endoscopist groups and AI. The endoscopists were divided into groups according to proficiency and experience with EUS: < 6 months of experience, junior ($n = 2$); 6 months to 5 years of experience, mid-level ($n = 3$); and ≥ 5 years of experience, expert ($n = 2$). Institutional review board approval was obtained for this study protocol (Gil Medical Center IRB No. GCIRB2020-126, Gangnam Severance Hospital IRB No. 3-2020-0085).

Data preparation (training and test data). The EUS data of AI development cohort were divided into training, validation, and test data sets, and the lack of data was supplemented through data augmentation. Data augmentation is defined as an algorithm that artificially expands the data when the training set data are insufficient.¹¹ Data augmentation was accomplished by transforming the original images into arbitrary combinations for flip, rotation, scale, and translation, respectively. Data augmentation was performed only when insufficient data were available to match the ratio when the number of data deviations was large; the ratio between the two clusters was augmented 5–10-fold if the training data were < 100 images. Data augmentation was applied to the training and validation sets, but not the test set (Table S1). Additionally, a separate set of cohort validation data was used for external validation of each model learned. In total, 83 EUS images were collected: 11 gallstones and 72 GB polyps (21 neoplastic, 51 non-neoplastic, 12 adenomatous, and 9 adenocarcinoma). No separate data enhancement was applied to the data set of external validation cohort.

Effective learning data were organized by preventing the inclusion of unnecessary areas through a pre-processing process. The region of interest (ROI) in the form of a box (20 mm $\times$ 20 mm) containing lesions was extracted from the EUS image and used in the experiment. Images that were cut to the same size were resampled to the same pixel length (256 $\times$ 256 pixels) to convert them into deep learning training data.

Convolutional neural network model for deep learning. The ResNet50 architecture, a convolutional neural network for deep learning, was used in this study. The ResNet50 is a structure in which the two-layer block of the existing 34-layer net has been replaced with a three-layer bottleneck block, thereby maximizing image classification performance due to the deep network layer and the low error rate.^{12,13} We used the weights of the ImageNet pre-trained model to initialize the models. The training hyperparameters were as follows for all models: batch size = 40, epochs = 300, and learning rate = 0.0001; this was applied equally to all discriminative models (Fig. 1). To understand and interpret the classification results of the trained model, the class activation map was obtained by visualizing the feature map of the last layer in the trained model^{14,15} (Fig. S1).

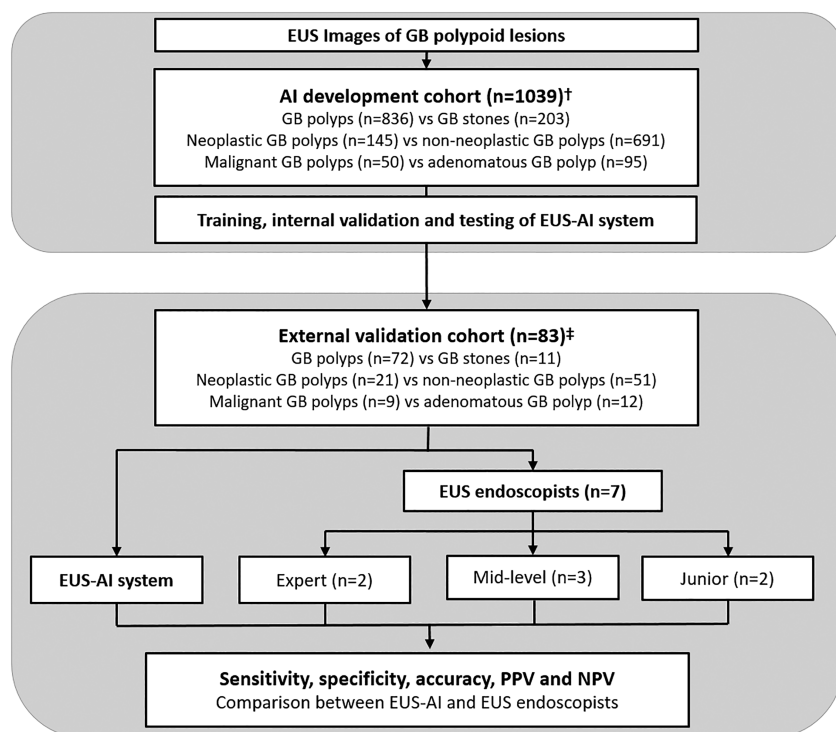


Figure 1 Patient flowchart. AI, artificial intelligence; EUS, endoscopic ultrasound; GB, gallbladder; NPV, negative predictive value; PPV, positive predictive value. [†]Number of images used for development of AI; [‡]represent number of patients used for external validation.

Statistical analysis. Three types of classification models were used for the EUS-AI system (model for GB polyp vs gallstones, model for neoplastic polyps vs non-neoplastic polyps, and model for adenocarcinoma vs adenomatous GB polyps); these models were trained using the deep learning algorithm. Each trained model was evaluated for performance through five cross-validations for robustness and data dependence.¹⁶ The models trained from each cross-validation produced true positives, true negatives, false positives, and false negatives according to the classification results; these data were used to calculate statistical measures of sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy. The area under the receiver operating characteristic curve (AUROC) was also calculated. Interobserver agreement was calculated using Cohen's kappa or Fleiss' kappa. Statistical analysis of clinical and demographic data was performed using SPSS software (version 23.0, IBM Corp., Armonk, NY, USA); $P < 0.05$ was considered statistically significant.

Results

Characteristics of patients and polypoid lesions of gallbladder in AI development cohort. Table 1 lists the baseline characteristics of patients with GB lesions, including GB polyps and gallstones, in the AI development cohort. The mean patient age was 53.3 ± 13.8 years, and 344 (56.3%) patients were women. When limited to GB polyps in this cohort, cholesterol polyps were most common (322/467 patients, 68.9%); neoplastic GB polyps were found in 99/467 patients (21.2%). Of the 1039 EUS images, 145 were neoplastic GB polyps, 691 were non-neoplastic GB polyps, and 203 were gallstones. Histopathological diagnosis revealed that the mean maximum diameters were

15.1 ± 4.2 mm for neoplastic GB polyps, 10.6 ± 3.1 mm for non-neoplastic GB polyps, and 11.1 ± 4.0 mm for gallstones. The neoplastic GB polyps were significantly larger than non-neoplastic GB polyps and gallstones ($P < 0.001$, $P < 0.001$), but there was no difference in size between non-neoplastic GB polyps and gallstones ($P = 0.20$). However, current guidelines suggest cholecystectomy for GB polyps > 10 mm¹⁷; therefore, all patients included in this cohort underwent surgery, despite significant differences in size.

Diagnostic performance of EUS-AI system using the AI development cohort. The diagnostic capability of the EUS-AI system was verified using the test data set in the AI development cohort (Table 2). In diagnostic step 1, for differentiation of GB polyps and gallstones, sensitivity was 98.4%, specificity was 84.2%, PPV was 96.3%, NPV was 92.9%, and accuracy was 95.7%. The AUROC of step 1 was 0.99 (95% confidence interval [CI], 0.98–0.99). In diagnostic step 2, for differentiation of neoplastic and non-neoplastic GB polyps, sensitivity was 57.9%, specificity was 96.5%, PPV was 77.8%, NPV was 91.6%, and accuracy was 89.8%. The AUROC of step 2 was 0.89 (95% CI, 0.87–0.91). In diagnostic step 3, for differentiation of adenocarcinoma and adenomatous GB polyps, sensitivity was 89.5%, specificity was 68.0%, PPV was 84.2%, NPV was 77.3%, and accuracy was 82.1%. The AUROC of step 3 was 0.91 (95% CI, 0.82–0.99).

Comparison of diagnostic performance between humans and EUS-AI system using external validation cohort. Because we observed encouraging diagnostic performance results with the EUS-AI system in the AI development cohort, we compared human and AI diagnostic abilities in the external validation cohort. Diagnostic performances, including

Table 1 Characteristics of patient and gallbladder lesions in the AI development cohort and external validation cohort

Characteristics	GB polyp			Gallstone
	All	Neoplastic polyp	Non-neoplastic polyp	
AI development cohort				
Number of patients (images)	670 (1039)	99 (145)	368 (691)	203 (203)
Patients characteristics				
Age	53.3 ± 13.8	56.5 ± 13.9	51.2 ± 12.1	55.3 ± 16.0
Sex (M/F)	326/344	45/54	192/176	89/114
Lesion characteristics (images)				
Size (mean ± SD)	11.4 ± 3.9	15.1 ± 4.2	10.6 ± 3.1	11.1 ± 4.0
Cholesterol polyp/adenomyomatosis/etc.			638/41/12	
Adenocarcinoma/adenomatous polyps		50/95		
External validation cohort				
Number of patients (images)	83 (83)	20 (20)	52 (52)	11 (11)
Patients characteristics				
Age	53.3 ± 13.3	61 ± 12.5	49.8 ± 11.8	54.9 ± 15.9
Sex (M/F)	37/46	12/8	18/34	5/6
Lesion characteristics (images)				
Size (mean ± SD)	11.8 ± 4.2	15.0 ± 4.1	10.9 ± 3.6	10.2 ± 5.9
Cholesterol polyp/adenomyomatosis/etc.			45/5/2	
Adenocarcinoma/adenomatous polyps		9/11		

AI, artificial intelligence; F, female; GB, gallbladder; M, male; SD, standard deviation.

Table 2 Diagnostic performance of EUS-AI system using train, validation, test set of the AI development cohort according to various diagnostic steps

		Train	Validation	Test
Step 1: Differential diagnosis between GB polyps (<i>n</i> = 836) [†] and gallstones (<i>n</i> = 203)	Sensitivity (%)	100	100	98.4
	Specificity (%)	99.3	99.1	84.2
	PPV (%)	99.3	99.1	96.3
	NPV (%)	100	100	92.9
	Accuracy (%)	99.7	99.5	95.7
	AUC (95% CI)	—	—	0.990 (0.984–0.994)
Step 2: Differential diagnosis between neoplastic (<i>n</i> = 145) and non-neoplastic (<i>n</i> = 691) GB polyps	Sensitivity (%)	100	100	57.9
	Specificity (%)	98.1	98.4	96.5
	PPV (%)	98.2	98.5	77.8
	NPV (%)	100	100	91.6
	Accuracy (%)	99.1	99.2	89.8
	AUC (95% CI)	—	—	0.891 (0.868–0.913)
Step 3: Differential diagnosis between adenocarcinoma (<i>n</i> = 50) and adenomatous (<i>n</i> = 95) GB polyps	Sensitivity (%)	100	100	89.5
	Specificity (%)	100	100	68.0
	PPV (%)	100	100	84.2
	NPV (%)	100	100	77.3
	Accuracy (%)	100	100	82.1
	AUC (95% CI)	—	—	0.910 (0.819–0.999)

[†]*n*, number of images.

AI, artificial intelligence; AUC, area under the receiver operating characteristic curve; CI, confidence interval; EUS, endoscopic ultrasound; GB, gallbladder; NPV, Negative predictive value; PPV, Positive predictive value.

sensitivity, specificity, PPV, NPV, and accuracy (Table 3), were as follows. In diagnostic step 1, these values were 93.1%, 81.8%, 97.1%, 64.3%, and 91.6%, respectively, for EUS-AI; they were 74.7%, 97.9%, 86.1%, 96.2%, and 94.9%, respectively, for the endoscopists. In diagnostic step 2, these values were 33.3%, 96.1%, 77.8%, 77.8%, and 67.4%, respectively, for EUS-AI; they were 74.2%, 44.9%, 75.4%, 46.2%, and 65.3%, respectively, for the endoscopists. For diagnostic step 3, these values were 83.3%,

66.7%, 76.9%, 75.0%, and 76.2%, respectively, for EUS-AI; they were 51.8%, 21.8%, 32.6%, 40.3%, and 34.7%, respectively, for the endoscopists. The AUROCs of diagnostic probability for GB polyps, neoplastic GB polyps, and adenocarcinomas via the EUS-AI system were 0.95, 0.71, and 0.74, respectively (Fig. 2).

Considering proficiency and experience with EUS, the accuracy of the EUS-AI system was between the accuracies of mid-level (66.7%) and expert EUS endoscopists (77.5%) for the differential

Table 3 Diagnostic performance of EUS-AI system versus endoscopists in differential diagnosis of GB polyps using the external validation cohort ($n = 83$)

Confusion matrix					GB-AI system	Endoscopists			
						All	Expert	Mid-level	Junior
Step 1: Differential diagnosis between GB polyps and gallstones	AI	GB polyps	Ground truth		Sensitivity (%)	93.1	74.7	90.9	63.6
			GB polyps	Gallstones	Specificity (%)	81.8	97.9	97.9	100
			67	2	PPV (%)	97.1	86.1	87.5	100
		Gallstones	5	9	NPV (%)	64.3	96.2	98.6	95.6
					Accuracy (%)	91.6	94.9	97	96
					AUC (95% CI)	0.953 (0.862–1.0)			
Step 2: Differential diagnosis between neoplastic and non-neoplastic GB polyps	AI	Neoplastic	Ground truth		Sensitivity (%)	33.3	74.2	90.2	69.9
			Neoplastic	Non-neoplastic	Specificity (%)	96.1	44.9	47.6	58.7
			7	2	PPV (%)	77.8	75.4	80.9	80.4
		Non-neoplastic	14	49	NPV (%)	77.8	46.2	65.2	46.3
					Accuracy (%)	77.8	65.3	77.5	66.7
					AUC (95% CI)	0.707 (0.577–0.799)			
Step 3: Differential diagnosis between adenocarcinoma and adenomatous GB polyps	AI	Adenocarcinoma	Ground Truth		Sensitivity (%)	83.3	51.8	61.1	66.7
			Adenocarcinoma	Adenomatous	Specificity (%)	66.7	21.8	20.9	36.1
			10	3	PPV (%)	76.9	32.6	35.1	44.3
		Adenomatous	2	6	NPV (%)	75.0	40.3	50	57.4
					Accuracy (%)	76.2	34.7	38.1	49.2
					AUC (95% CI)	0.740 (0.653–0.847)			

AI, artificial intelligence; AUC, CI, confidence interval; EUS, endoscopic ultrasound; GB, gallbladder; NPV, negative predictive value; PPV, positive predictive value.

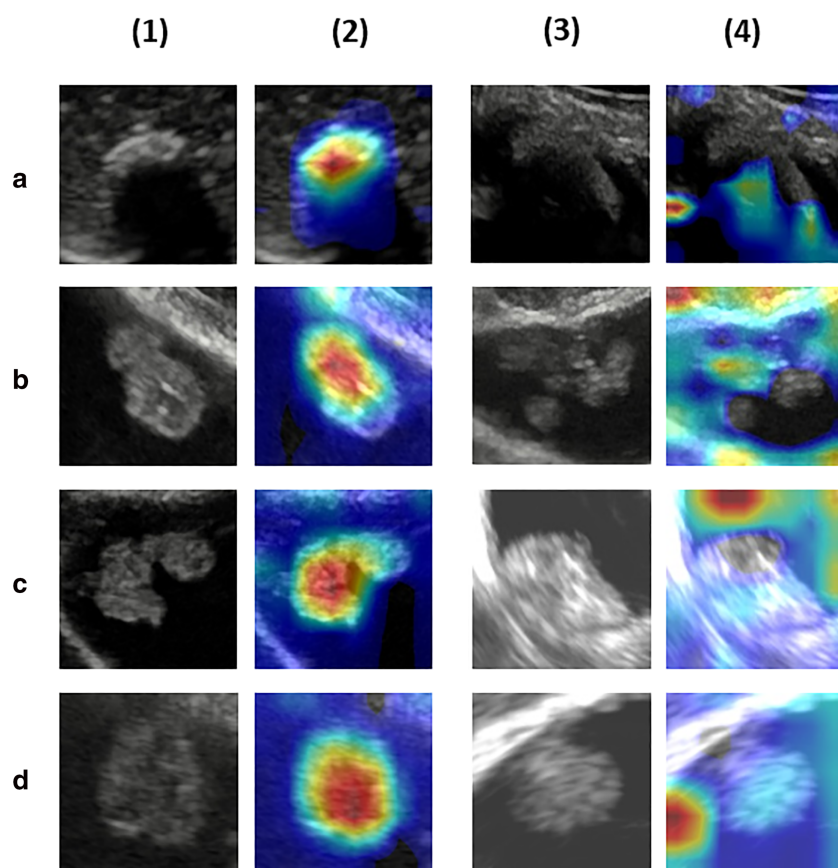


Figure 2 Class activation map (CAM) analyzes which part of the image affected the classification in the image classification through deep learning. This figure represents the CAM of the endoscopic ultrasound image classified as correct (1,2) and the image classified as incorrect (3,4) in each experiment. (a) gallstone; (b) gallbladder polyp; (c) non-neoplastic gallbladder polyp; (d) neoplastic gallbladder polyp.

diagnosis of neoplastic polyps and non-neoplastic polyps (Fig. 3). The accuracy of diagnosing adenocarcinoma via EUS-AI was 76.2%, which was higher than all levels of EUS endoscopists (16.7–49.2%). Furthermore, interobserver agreement between the endoscopists and EUS-AI was fair ($k = 0.22$). Among the endoscopists, interobserver agreement was relatively high for the expert EUS endoscopists ($k = 0.28$), but poor for the mid-level ($k = 0.19$) and junior endoscopists ($k = 0.01$).

Discussion

In this pilot study, we found that a deep learning-based EUS-AI algorithm was valuable for the differential diagnosis of GB polyps. The intuitive diagnosis of GB polyps involves the following steps: identification of GB polyps and exclusion of gallstones (step 1), differentiation of neoplastic and non-neoplastic polyps among GB polyps (step 2), and identification of adenocarcinoma among neoplastic polyps (step 3). We first distinguished GB stones from polyps. Although abdominal US and EUS are considered effective in this regard, this is not always the case. On US, gallstones smaller than 5 mm cannot be distinguished from polyps.^{18,19} Biliary sludge and small (< 5 mm) stones may be mistaken for polyps.^{20,21} Ultimately, EUS-AI must be able to identify neoplastic polyps, so in the first instance, it was necessary to distinguish GB stones from polyps.

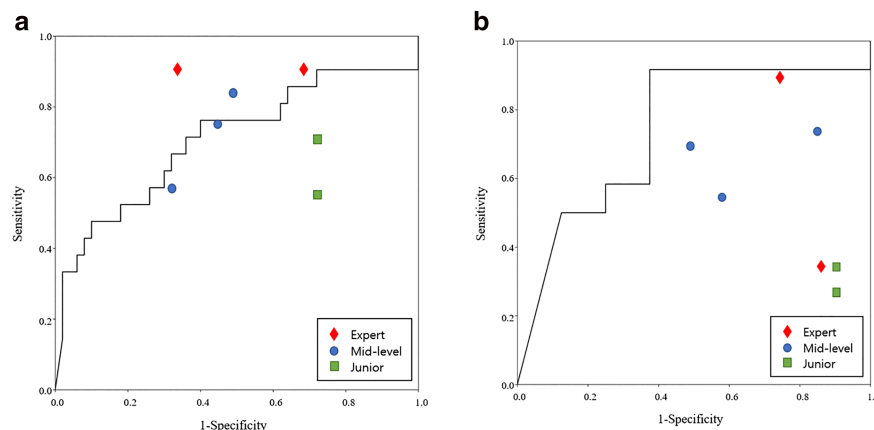
Notably, laparoscopic cholecystectomy is commonly performed for GB polyps > 10 mm in size; approximately one-third of those polyps are adenomatous.²² Furthermore, it is important to detect adenocarcinomas among neoplastic GB polyps; GB cancer, which invades the muscular layer, may require extended cholecystectomy. In our study, the sensitivity, specificity, PPV, NPV, and accuracy were calculated for these diagnostic steps of the EUS-AI system. In the AI development cohort, the respective AUROCs of steps 1, 2, and 3 were 0.99 (95% CI 0.98–0.99), 0.89 (95% CI 0.87–0.91), and 0.91 (95% CI 0.82–0.99); these were very encouraging data, indicating that the EUS-AI system is useful for objective diagnosis.

Because further verification of the usefulness of the EUS-AI system is required, we performed external validation to compare diagnostic performances using a multicenter validation cohort of 83 patients with GB lesions. In this external validation cohort, the AUROCs of the EUS-AI system, in terms of the diagnostic

probabilities of step 1 (identification of GB polyps and exclusion of gallstones), step 2 (differentiation of neoplastic and non-neoplastic GB polyps), and step 3 (diagnosis of adenocarcinoma among neoplastic GB polyps), were 0.95, 0.71, and 0.74, respectively. This reduction in diagnostic capacity of steps 2 and 3, compared with that of the AI development cohort, presumably occurred for two reasons: (i) the number of EUS images in the AI development cohort was insufficient for overall EUS-AI training, and (ii) EUS images of the external validation cohort were likely to have different visual data that the EUS-AI system had not experienced during the initial EUS-AI learning process. Notably, based on comparisons of AI and human diagnostic abilities in the external validation cohort, the EUS-AI system was superior to EUS endoscopists in the diagnosis of neoplastic GB polyps and adenocarcinomas. Considering proficiency and EUS experience, the accuracy of the EUS-AI system was between the accuracies of mid-level and expert EUS endoscopists for the differential diagnosis of neoplastic and non-neoplastic polyps. Thus, the accuracy of EUS-AI system may correspond to that of a EUS endoscopist with at least 5 years of experience. If the EUS-AI system is continuously provided with additional training EUS images, its diagnostic performance will further improve.

In clinical practice, previous studies have supported the risks for neoplastic change, which have been used to assess preoperative diagnosis.^{1,2,4,23,24} The diagnostic rates for neoplastic polyps of abdominal US, EUS, and CT are listed below. The diagnostic sensitivity of high-resolution US was comparable with that of EUS (90 and 86%, respectively); both of those modalities were better than CT (72%) for evaluating gallbladder polypoid lesions.^{25,26} Polyp size is the best predictor of malignancy; several other features on EUS images are used for preoperative diagnosis. However, excluding the size criterion, these findings on EUS images showed inadequate performance because many parameters in GB polyps are subjective (e.g. hyperechoic spots, microcysts, central hypoechoic foci, and Doppler flow). In addition, the interpretation of EUS and contrast enhanced harmonic-EUS images by visual assessment is subjective; an objective analytical technique for discrimination of GB diseases is required. The EUS-AI system can objectively determine the neoplastic risk of GB polyps before cholecystectomy via intuitive imaging analysis. Moreover, because the size of the polyp is stored in EUS images by the placement of size information into the EUS pixel, connected with the EUS

Figure 3 Receiver operating characteristic (ROC) for the image analysis based on external validation data sets ($n = 83$). (a) ROC curve for differentiation between neoplastic and non-neoplastic gallbladder polyps. (b) ROC curve for differentiation between adenocarcinoma and adenomatous gallbladder polyps.



bar ruler, EUS-AI can complete the diagnostic process with consideration of lesion size.

This study is the first to apply AI for the EUS diagnosis of GB disease, although CT or abdominal US were applied in previous pilot studies.^{27,28} AI has been used in many medical fields such as ophthalmology, dermatology, and oncology.^{29–32} Recently, an AI diagnostic algorithm using endoscopic images has been developed for gastrointestinal diseases such as peptic ulcers, colorectal polyps, and inflammatory bowel disease.^{10,33–36} Regarding AI for EUS images, a few reports have shown the usefulness of AI for pancreatic neoplasms.^{37,38} Similar to our AI analysis tools, Kuwahara *et al.* used a convolutional neural network architecture and demonstrated the superiority of the AI algorithm for the diagnosis of malignant intraductal papillary mucinous neoplasms.³⁹

The current study indicated that the EUS-AI system is useful for objective diagnosis of neoplastic GB polyps; however, there were several limitations. First, the retrospective design and limited sample size have inherent limitations. We used data augmentation to compensate for the lack of AI training data. To minimize artificial changes in the original image, we used a rigid transformation method for data augmentation. However, data augmentation are considered a temporary measure to compensate for a small sample size; greater numbers of patients are required in future studies for a reliable AI model. Second, because our analysis was limited to representative EUS images, potential EUS findings may have been exaggerated or missed. Because the EUS test observes target lesions in real time, future AI studies are required to assess moving images. Lastly, the current study only included GB polyps with a maximum diameter of 7–20 mm for the AI analysis. Laparoscopic cholecystectomy is considered a simple and standard treatment strategy for polyps > 10 mm. Thus, there is a fundamental concern regarding whether additional EUS inspection is required. However, even for 10–20 mm GB polyps, because many comprise both non-neoplastic GB polyps and small gallstones, EUS AI analysis is expected to reduce unnecessary surgeries. Third, non-neoplastic GB polyps were histologically confirmed by cholecystectomy. However, polyp images may differ between patients with non-neoplastic GB polyps evaluated by cholecystectomy compared with those assessed using other techniques. Therefore, the utility of EUS-AI should be confirmed in patients with non-neoplastic GB polyps who did not undergo cholecystectomy. Finally, the AUROC of diagnostic probability for neoplastic GB polyps via the EUS-AI system was 0.71, which may not have a relatively sufficient clinical impact. Therefore, further large-scale studies are needed to develop the EUS-AI system with improved accuracy because the feasibility of the EUS-AI system for the diagnosis of neoplastic GB polyps was confirmed in this study.

In conclusion, the newly developed EUS-AI system showed favorable performance for diagnosis of neoplastic GB polyps and adenocarcinomas, with performance comparable to that of EUS endoscopists. Because the application of AI has been slow in the EUS field compared with other endoscopic methods, additional efforts are needed to overcome the limitations of EUS, such as the subjective interpretation and lack of standardization. It is expected that the applications of AI in the EUS field will increase with further prospective multicenter studies and advances in technology that enable analysis of EUS videos in real time.

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Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Composition of deep learning training dataset used for each classification model.

Figure S1. ResNet-50 architecture.