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Original Article

The Potential Role of the Rapid Urease Test with the Sweeping Method in the Gray Zone of the Urea Breath Test after *Helicobacter pylori* Eradication

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Background/Aims: Although the urea breath test (UBT) is widely used as a representative monitoring test after *Helicobacter pylori* eradication, false-negative results can occur because of the gray zone related to its cutoff value. This study aimed to compare the diagnostic performances of the rapid urease test (RUT), the RUT with sweeping method, and the UBT, and to investigate the role of the sweeping method in the gray zone of UBT values.

Methods: We retrospectively reviewed 216 patients who received standard first-line *H. pylori* eradication treatments (n=216). All participants underwent to testing using the sweeping method and UBT on the same day. The sensitivity, specificity, and accuracy were analyzed to compare the two methods.

Results: The sensitivity (0.537 vs 0.806, p=0.002) and accuracy (0.843 vs 0.870, p=0.026) of the UBT were inferior to those of the sweeping method. A total of 31 individuals tested positive for *H. pylori* according to the UBT, whereas 54 individuals tested positive according to the sweeping method. In the group for which the gold standard definition indicated *H. pylori* positivity but UBT results were negative (n=31), all individuals had a UBT value under 2.5‰. In the multivariate logistic regression model, a UBT value of 1.4‰ to 2.5‰ increased the risk of false-negative results by 6.5 times (odds ratio, 6.5; 95% confidence interval, 2.077 to 20.288; p=0.001).

Conclusions: After *H. pylori* eradication, false-negative results can occur for individuals undergoing the UBT, primarily for values below the UBT cutoff. The RUT with the sweeping method can potentially help detect *H. pylori* in the gray zone of the UBT, improving diagnostic accuracy. **(Gut Liver, 2025;19:355-363)**

Key Words: Urea breath test; Rapid urease test; Sweeping method; Eradication; Urea breath test cutoff values

INTRODUCTION

Helicobacter pylori is classified as a class 1 carcinogen by the World Health Organization and is the most potent risk factor for the development of gastric cancer.[1,2] This organism can survive in the acidic environment of the stomach mucosa, which provides a strong defense mechanism against external pathogens. *H. pylori* induces chronic inflammation in the surface epithelium and is associated with various gastric diseases, including gastric cancer.[3-5] Therefore, the accurate diagnosis and treatment of this strain are very important.

In addition to initiating eradication therapy for the management of *H. pylori* infections, ensuring the complete removal of the strain after treatment is even more important. The urea breath test (UBT) is the most representative method used to confirm eradication.[6] This method is highly sensitive and specific, and it is commonly used because it is noninvasive and does not require endoscopic follow-up. However, because it is a qualitative test based on

a cutoff value (2.5‰), the issue of false negatives persists.[7] Therefore, there is a gray zone in the UBT results, and it is recommended that the cutoff value be lowered for a more accurate diagnosis.[8] Test results may vary depending on factors such as the amount of urease present, type of reagent, test equipment, patient's respiratory level, and fasting duration.[9]

The rapid urease test (RUT) with the sweeping method has higher sensitivity and accuracy than RUT with the conventional biopsy sampling method.[10-12] Patients with peptic ulcers and gastric cancer require follow-up endoscopy after eradication. Under these conditions, RUT, along with the sweeping method, may replace UBT as a suitable monitoring test after *H. pylori* eradication. Furthermore, despite the increasing importance of antibiotic susceptibility testing in the development of *H. pylori* eradication strategies,[13,14] the UBT is unable to yield antibiotic susceptibility testing results; in contrast, previous studies have confirmed that the sweeping method can yield information regarding the antibiotic susceptibility testing and thus, be useful for establishing suitable treatment regimens.[11,12] Therefore, in the present study, we performed a retrospective reanalysis of the published data[12] to compare the diagnostic performances of the sweeping test and UBT. In addition, we aimed to evaluate the effectiveness of RUT to detect *H. pylori* using the sweeping method in the gray zone of the UBT and determine whether this method can address the limitations of the UBT.

MATERIALS AND METHODS

1. Study design and patients

This retrospective single-center study was conducted at Ajou University Hospital (Suwon, Republic of Korea) between March 2019 and May 2022. We conducted a retrospective reanalysis of previously reported data,[12] and all data were fully anonymized for analysis. All enrolled patients were scheduled to undergo upper endoscopy after first-line standard *H. pylori* eradication. The exclusion criteria were as follows: age <20 years, *H. pylori* eradication history, history of antibiotic or probiotic use within 6 months, history of proton pump inhibitor use within the last 4 weeks, severe coagulopathy, pregnancy, and previous stomach operations, including subtotal gastrectomy. The study protocol was approved by the Institutional Review Board of Ajou University Hospital (approval no. AJOUIRB-OBS-2021-485), and the requirement for written informed consent was waived because of the retrospective nature of the study.

2. Diagnostic tools for *H. pylori* detection after eradication

All patients received eradication treatment with a first-line standard triple regimen consisting of a standard dose of a proton pump inhibitor, amoxicillin 1 g, and clarithromycin 500 mg, administered twice daily for 7 days.[15] The sweeping method involves sweeping the mucosa with a swab material instead of biopsy tissue sampling (Fig. 1). The sensitivity and accuracy of the test were confirmed in previous studies, which provide detailed information about the method.[10,12] For ^{13}C-UBT, patients were instructed to fast for at least 4 hours before the examination. Breath samples were collected with the patient in a sitting position using special breath collection bags at two time points: before (baseline) and 30 min after tablet-based administration of 100 mg of ^{13}C-urea (UBiTkit; Otsuka Pharmaceutical Co. Ltd., Tokyo, Japan). The samples were analyzed using an isotope-selective, nondispersive infrared spectrometer (UbiT-IR 300; Otsuka Pharmaceutical Co. Ltd.). The cutoff value was determined to be 2.5‰, as recommended by the manufacturer, and a $^{13}CO_2$ content of ≥2.5‰ was considered positive for *H. pylori* detection. The gray zone of the UBT value was defined as 1.4‰ to 2.4‰.

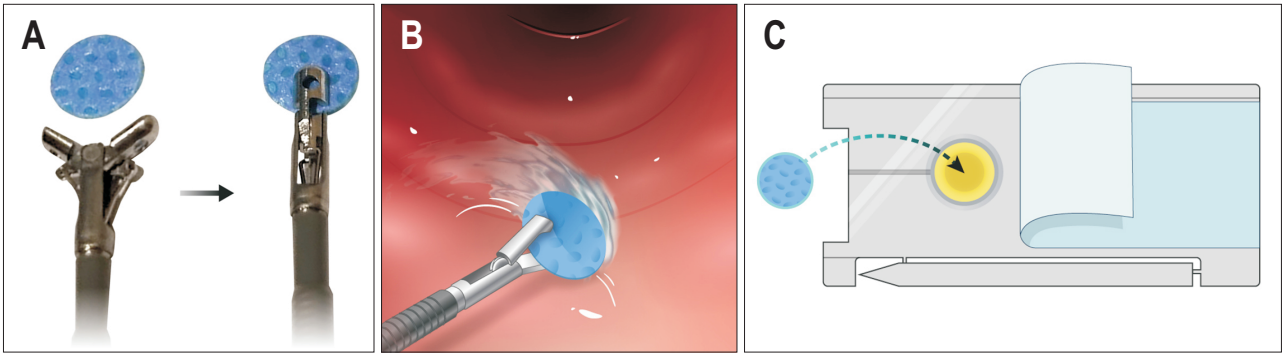

Fig. 1. Illustration of the rapid urease test with the sweeping method. (A) Grasping of the round (diameter, 6 mm) swab material using the endoscopic forceps. (B) Sweeping the stomach with the swab held with the forceps. (C) Placement of the swab during the rapid urease test.

All participants underwent the following confirmation tests to establish a gold standard definition of *H. pylori* true infection: RUT with the conventional tissue sampling method, histopathology including immunohistochemical staining, and formalin-fixed paraffin-embedded (FFPE) tissue polymerase chain reaction (PCR). In cases of inconsistent results between the two RUT methods (sweeping and conventional sampling methods), PCR was additionally performed on both the swab material and tissue samples. *H. pylori* confirmation (gold standard definition) was defined as follows: (1) positive in one or more of the remaining tests, excluding the sweeping method and UBT; (2) all negative but positive in both the sweeping method and UBT. All test negative except for positive results in both the sweeping method and UBT. All tests to confirm eradication were performed 4 weeks after the completion of drug administration.[15]

3. RUT with the tissue sampling method

Tissue samples were collected from the antrum (anterior wall of the mid-antrum) and the corpus (middle portion of the greater curvature). The locations from which the tissue samples were collected did not overlap with those used in the sweeping method.

4. Histopathological examination

We obtained the following five samples according to the updated Sydney system: (1) two tissue samples from the antrum; (2) one sample from the lesser curvature side of the corpus (4 cm proximal to the angulus); (3) one sample from the greater curvature side of the mid-portion in the corpus; and (4) one sample from the incisura angularis.[16] For histopathological examination, hematoxylin and eosin, Giemsa, and immunohistochemical staining were performed.

5. FFPE tissue-PCR

Real time-PCR was performed using FFPE tissue blocks to analyze additional tissues for lesion diagnosis. In patients without lesions (n=49), the tissues were sampled from the normal mucosa. DNA was extracted using a QIAamp DNA Tissue Kit (Qiagen, Hilden, Germany). A U-TOP HPy ClaR Detection Kit (SeaSun Biomaterials, Daejeon, Republic of Korea) was used to confirm *H. pylori* infection. Subsequently, real time-PCR was performed using a CFX96 Touch RealTime-PCR Detection System (Bio-Rad, Hercules, CA, USA). *H. pylori* infection was determined based on the fluorescence signal of the detection probes, and the corresponding melting temperature after real time-PCR.

6. Study outcomes

The primary outcome of this study was the comparison of sensitivity between RUT using the sweeping method and ^{13}C-UBT for evaluating *H. pylori* eradication. The secondary objective was to analyze the reasons for the differences in the sensitivities of these two methods.

7. Statistical analysis

Continuous and categorical variables are expressed as the mean (standard deviation) and number (frequency), respectively. The sensitivity, specificity, accuracy, positive predictive value, and negative predictive value were calculated along with 95% confidence intervals (CIs). The receiver operating characteristic curve was calculated with the corresponding 95% CI, and the statistical difference in the area under the receiver operating characteristic curve (AUROC) values obtained for the two methods was evaluated. Differences between groups were compared using a t-test or analysis of variance for continuous variables and the chi-square test for categorical variables. The p-value was adjusted using Bonferroni correction, if necessary. Logistic regression models were used to evaluate the risk factors associated with patients identified using the gold standard definition but had negative UBT results. Statistical analyses were conducted using SAS statistical software (SAS Institute, Cary, NC, USA), and a two-tailed $p<0.05$ was considered statistically significant.

RESULTS

1. Study population and baseline characteristics

In total, 216 patients were enrolled in this study (Fig. 2). The mean age of the patients was 58.8±11.0 years, and 67.6% (n=146) were male. The most common reason for eradication was to prevent recurrence after endoscopic removal of the early gastric neoplasm (n=104, 48.2%). Gastric adenomas accounted for the highest proportion of endoscopic diagnoses (n=58, 26.9%). Interestingly, gastric ulcers (n=37) were 3.4 times more common than duodenal ulcers (n=11). Normal mucosa without atrophy was observed in 15.7% (n=34) of patients. The eradication success rate after first-line standard treatment was 68.1% (n=147), according to our gold standard definition. The baseline characteristics of the enrolled patients is provided in Table 1.

2. Comparison between two diagnostic methods (RUT with the sweeping method vs UBT)

The sensitivity (0.806 [95% CI, 0.691 to 0.892] vs 0.537 [95% CI, 0.411 to 0.660], p=0.002) and accuracy (0.870 [95% CI, 0.818 to 0.912] vs 0.843 [95% CI, 0.787 to 0.888],

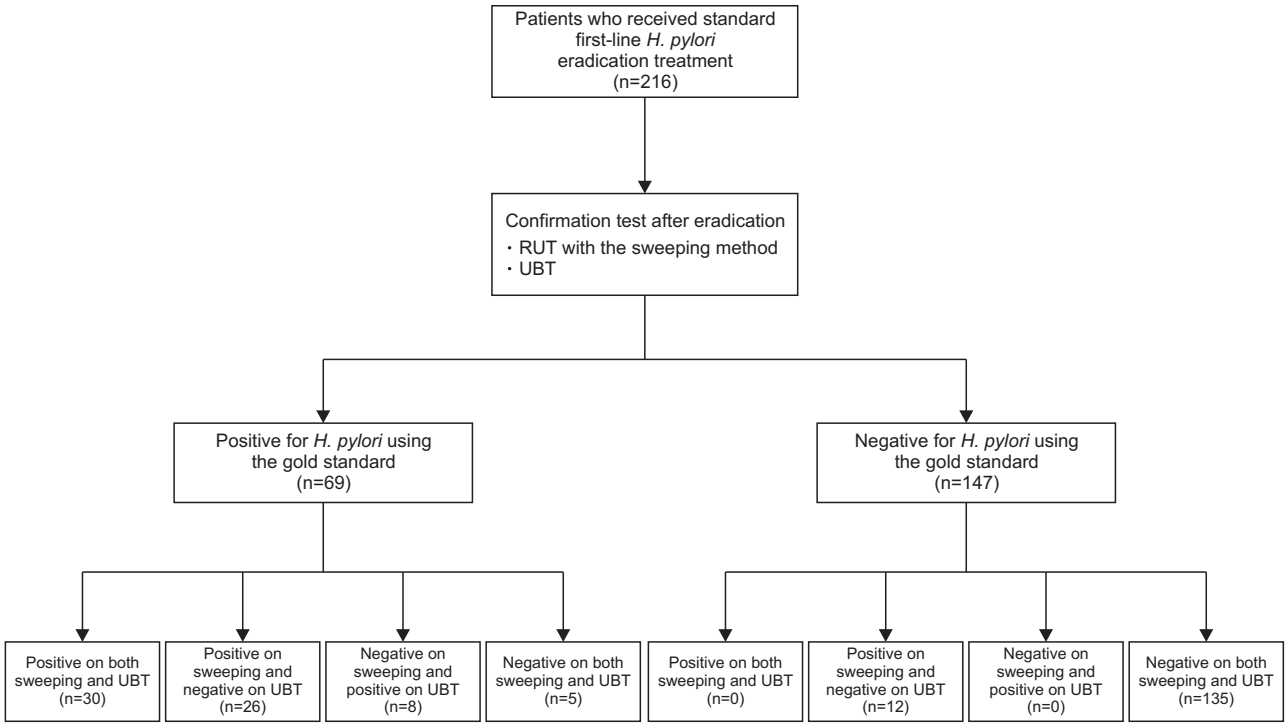

Fig. 2. Study flow for enrolled patients and the results of *Helicobacter pylori* tests after eradication treatment. RUT, rapid urease test; UBT, urea breath test.

Table 1. Baseline Characteristics of the Enrolled Patients (n=216)

Characteristic	Value
Age, mean±SD, yr	58.8±11.0
Male sex	146 (67.6)
BMI, mean±SD, kg/m^2	24.7±3.2
Diagnosis	
Gastric ulcer	37 (17.1)
Duodenal ulcer	11 (5.1)
Early gastric neoplasm	
Gastric adenoma	58 (26.9)
Early gastric cancer	46 (21.3)
MALT lymphoma	15 (6.9)
Normal	49 (22.7)
Presence of atrophy	63 (29.2)
Presence of intestinal metaplasia	119 (55.1)

Data are presented as number (%) unless otherwise indicated.
BMI, body mass index; MALT, mucosa-associated lymphoid tissue.

p=0.026) of the sweeping method were significantly higher than those of UBT. However, the specificity of the sweeping method was lower than that of the UBT (0.899 [95% CI, 0.839 to 0.943] vs 0.980 [95% CI, 0.942 to 0.996], p=0.001). The positive predictive value was significantly lower for the sweeping method than compared to UBT (0.783 [95% CI, 0.667 to 0.873] vs 0.923 [95% CI, 0.791 to 0.984], p=0.017); however, the negative predictive value was significantly higher for the sweeping method than for UBT (0.912 [95% CI, 0.854 to 0.952] vs 0.825 [95% CI, 0.761 to 0.878], p=0.006). Therefore, the sweeping method had a higher sensitivity, accuracy, and negative predictive value than UBT. We performed an AUROC analysis to evaluate the overall diagnostic performance of the two methods. The AUROC for the sweeping method was higher than that for UBT (0.853 vs 0.759, p=0.026).

A comparison of the diagnostic performance of the two methods under various conditions is shown in Fig. 3. The sensitivity of the sweeping method was superior to that of UBT under all conditions except for ulcers. The difference in sensitivity between the two methods was more pronounced for intestinal metaplasia and cancer. The sensitivity of the sweeping method was significantly higher than that of UBT in patients with intestinal metaplasia (0.833 [95% CI, 0.672 to 0.936] vs 0.472 [95% CI, 0.304 to 0.645], p=0.003). The sensitivity of the sweeping method was 2.7 times higher than that of UBT under cancer conditions (0.800 [95% CI, 0.444 to 0.975] vs 0.300 [95% CI, 0.060 to 0.652], p=0.025). Interestingly, *H. pylori* eradication is important for peptic ulceration; however, no difference was observed between the two methods. Among 177 patients who tested negative on UBT, 38 (21.4%) tested positive using the sweeping method. Among these patients who tested positive, 26 (14.7%) were confirmed to have the infection. Therefore, the sweeping method is superior to UBT in confirming *H. pylori* eradication.

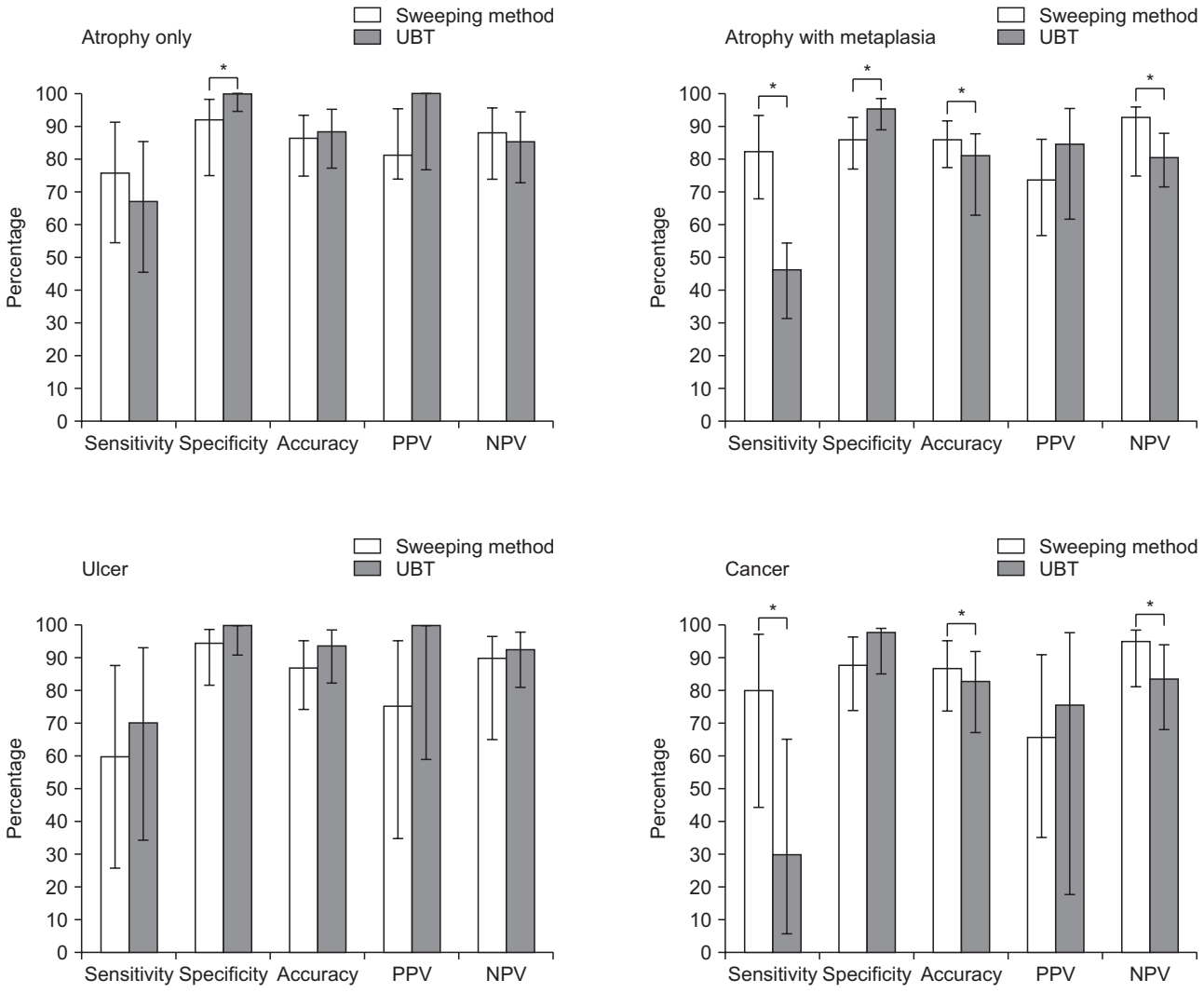

Fig. 3. Assessment of the diagnostic performance of the rapid urease test using the sweeping method and the UBT for the diagnosis of *Helicobacter pylori* infection after eradication treatment. All bars represents the corresponding 95% confidence intervals. UBT, urea breath test; PPV, positive predictive value; NPV, negative predictive value. *p<0.05.

3. Role of RUT with the sweeping method in cases of missed detection of *H. pylori* in UBT

Of the total patients, 31 were *H. pylori* positive based on the gold standard definition but were not detected using the UBT. We compared the demographic and clinical characteristics between these patients (group 1) and the others (group 2) (Table 2). All patients in group 1 had a UBT value <2.5‰, which is considered to indicate successful *H. pylori* eradication. However, 26 of the 31 patients (83.9%) in group 1 tested positive for *H. pylori* using RUT with the sweeping method. Additionally, seven of these patients were included in the gray zone of the UBT values (1.4‰ to 2.4‰), which represented a significantly higher percentage than that in group 2 (22.6% vs 4.3%, p=0.002). Multiple logistic regression analysis showed that the UBT gray zone was significantly associated with an increased risk of being classified in group 1 (odds ratio, 6.453; p=0.001) (Table 3). These findings indicate that UBT alone cannot detect *H. pylori* perfectly, hence cannot determine the success of eradication treatment, and that readjusting the cutoff level for UBT may be required to improve the accuracy of eradication success.

DISCUSSION

UBT is the most representative noninvasive test for confirming successful *H. pylori* eradication.[2] In contrast, the most commonly used invasive method for *H. pylori* testing is RUT. However, owing to its low sensitivity after *H. pylori* eradication in clinical practice, UBT is preferred, even in patients requiring endoscopic follow-up. Despite this, there are cases in which *H. pylori* is detected by alternative tests,

Table 2. Comparison of the Demographic and Clinical Characteristics between the Two Groups

Characteristic	Group 1 (n=31)	Group 2 (n=185)	p-value
Age			0.444
<60 yr	14 (45.2)	98 (53.0)	
≥60 yr	17 (54.8)	87 (47.0)	
Male sex	10 (32.3)	60 (32.4)	1.000
BMI, median (IQR), kg/m^2	24.4 (23.3–25.7)	24.6 (22.6–26.5)	0.943
Medical history			
Hypertension	18 (58.1)	69 (37.3)	0.046
Diabetes	8 (25.8)	37 (20.0)	0.477
Cerebrovascular accident	1 (3.2)	6 (3.2)	1.000
Cardiovascular disease	1 (3.2)	5 (2.7)	1.000
Diagnosis			0.538
Normal	9 (29.0)	40 (21.6)	
Peptic ulcer	2 (6.5)	35 (18.9)	
Gastric adenoma	1 (3.2)	10 (5.4)	
Gastric cancer	9 (29.0)	49 (26.5)	
MALT lymphoma	7 (22.6)	39 (21.1)	
UBT value under 2.5%	31 (100.0)	145 (78.4)	0.002
UBT gray zone (1.4%–2.4%)	7 (22.6)	8 (4.3)	0.002
Fluid amount in the stomach			0.152
Scanty	10 (32.3)	36 (19.5)	
Other*	21 (67.7)	149 (80.5)	
Atrophy	7 (22.6)	56 (30.3)	0.522
Atrophy with metaplasia	19 (61.3)	100 (54.1)	0.559
Metaplasia or gastric cancer	20 (64.5)	108 (58.4)	0.560
Presence of clarithromycin resistance	5 (18.5)	12 (36.4)	0.158
Failure at the second-line eradication treatment	9 (45.0)	21 (56.8)	0.420

Data are presented as number (%) unless otherwise indicated.
Group 1, patients with *Helicobacter pylori* positivity identified using the gold standard definition but not by the UBT; Group 2, other patients; BMI, body mass index; IQR interquartile range; MALT, mucosa-associated lymphoid tissue; UBT, urea breath test.
*Other included minimal to moderate amounts of gastric fluid.

such as biopsy sampling, even when UBT tests are negative. These false-negative UBT results could be attributed to the effects of medications such as proton pump inhibitors and antibiotics, issues with breath collection during the UBT, or the fasting period before the test.[9] Another factor could be the cutoff value used in UBT.[7,8] The UBT is a qualitative test that interprets results based on a cutoff value that is typically set at 2.5‰; however, if the test result is lower than 2.5, other more sensitive tests may yield positive results. The area around 2.5‰ cutoff is referred to as the UBT gray zone, where the incidence of false negatives may be higher. We investigated the characteristics of the false-negative cases that were not detected by UBT using the highly sensitive sweeping method in patients who underwent various *H. pylori* detection tests simultaneously. In addition, the diagnostic performance of UBT was compared. The sweeping method showed higher sensitivity and accuracy than the UBT in patients who underwent eradication treatment, with 1.5 times higher sensitivity. We divided the patients into two groups: those tested positive by the gold standard definition but not by UBT (group 1) and the remaining patients (group 2). The two groups showed differences in UBT values under 2.5‰ and in the UBT gray zone. The odds ratio for the 1.4‰ to 2.4‰ range affecting group 1 was 6.5. The UBT cutoff values vary by country, and there is no consensus regarding the UBT gray zone value.[17] Thus, unestablished reference values can lead to inaccurate detection of *H. pylori* infections. This indicates that UBT alone is insufficient to perfectly detect *H. pylori*, and the UBT cutoff point may need to be readjusted for a more accurate adjustment.

The sweeping method showed superior sensitivity and accuracy to RUT compared to the tissue sampling method.[10-12] This is a rapid method for confirming results without tissue samples. The present study confirmed that the sweeping method has superior sensitivity and accuracy compared with UBT under various conditions. *H. pylori*-related atrophic gastritis and intestinal metaplasia have been reported to increase cancer incidence.[18,19] Therefore, attention should be paid to the diagnostic performance of the sweeping method, which demonstrates high sensitivity for conditions such as premalignant lesions. As sensitivity increases, the false-positive rate may also increase. However, treating these cases as false-positives and administering eradication therapy is preferable to leaving them untreated as false-negatives, which could pose the risk of cancer. Moreover, patients with certain conditions, such as peptic ulcers and gastric cancer, require endoscopies for follow-up examinations. In these situations, performing the sweeping method during follow-up endoscopy as a post-eradication evaluation could be a more time- and cost-effective alternative.

Because the sweeping method collects *H. pylori* from a broad area of the gastric mucosa using a swab, it is presumed to have high sensitivity by reducing the false-negative rate. RUT requires the presence of at least >10^5 *H. pylori* for a color change.[20,21] In a recent study, samples obtained using the sweeping method had a bacterial load up to 31 times higher than that obtained using a biopsy sample.[11] Therefore, the sweeping method exhibited higher sensitivity for *H. pylori* detection than the conventional tissue sampling method. Therefore, it is presumed that the sweeping method can detect cases judged as negative because of the cutoff value in the UBT. In our study, 31 patients with *H. pylori* infection were not detected by UBT, but the sweeping method identified *H. pylori* in 26 of these patients (83.9%). Interestingly, six patients had a UBT

Table 3. Logistic Regression Analysis of the Risk of Patients Who Were Identified Using the Gold Standard Definition but Had Negative UBT Results

Variable	Univariate		Multivariate	
	Odds ratio (95% CI)	p-value	Odds ratio (95% CI)	p-value
Age				
<60 yr	Reference			
≥60 yr	1.4 (0.638–2.975)	0.422		
Female sex	1.0 (0.424–2.192)	0.985		
BMI				
<25 kg/m^2	Reference			
≥25 kg/m^2	0.7 (0.311–1.533)	0.389		
Atrophy only	0.7 (0.255–1.578)	0.386		
Atrophy with metaplasia	1.3 (0.624–3.002)	0.455		
Ulcer	0.3 (0.077–0.999)	0.082	0.4 (0.083–1.161)	0.127
Gastric cancer	1.1 (0.410–2.609)	0.850		
UBT gray zone*	6.5 (2.095–19.605)	0.001	6.5 (2.077–20.288)	0.001
Presence of clarithromycin resistance	0.4 (0.111–1.272)	0.133		
Fluid amount in the stomach				
Scanty	Reference		Reference	
Other†	0.5 (0.224–1.210)	0.112	0.5 (0.215–1.245)	0.125
Failure at the second-line eradication treatment	0.6 (0.215–1.245)	0.125		

CI, confidence interval; BMI, body mass index; UBT, urea breath test.
*UBT value 1.4‰–2.4 ‰; †Other included minimal to moderate amounts of gastric fluid.

value in the range of 1.4‰ to 2.4‰, while 20 values were under 1.4‰. In actual clinical practice, it is possible that a considerable number of patients receive false-negative results on UBT, which could be erroneously determined as *H. pylori* eradication success. Consequently, the accuracy of the UBT may have been overestimated. Our results show that simply changing the bacterial collection method can lead to high sensitivity in detecting *H. pylori*, which is the most potent risk factor for gastric cancer. This study is expected to make significant contribution to clinical practice.

The sweeping method appears to outperform UBT in sensitivity but shows lower specificity and higher false-positive rates. Low specificity is linked to the occurrence of false-positives. Although we employed various tests for the definition of the gold standard, the stool antigen test or culture was not performed. These limitations made it challenging to accurately evaluate the false-positive results obtained using the sweeping method. However, we conducted additional eradication treatments for the false-positive cases, and follow-up testing using the sweeping method showed negative results in all cases, except one. In clinical practice, we recommend considering eradication if a positive result is obtained using the sweeping method, rather than focusing on the possibility of a false positive, from the perspective of removing *H. pylori*, which is a critical risk factor for gastric cancer.

In the present study, the sweeping method demonstrated higher sensitivity and accuracy, particularly in patients with precancerous conditions, such as intestinal metaplasia, and cancer. This result is similar to our previous findings in the general population.[10] Although we were not able to experimentally elucidate the cause, we speculate that atrophy and metaplasia are likely to be present in cancer or precancerous conditions and that this environment might have affected the exocrine function via cellular plasticity and reprogramming of the gland.[22] This is also induced by *H. pylori*, and these environments are known to affect *H. pylori* clustering or intensity.[23,24] Because the sweeping method can cover a large area of the gastric mucosa, it is assumed to be more sensitive than the other methods. The strength of the sweeping method may have been more pronounced in situations where the bacterial load was reduced after eradication. Moreover, we speculate that the detection of *H. pylori* in the UBT gray zone using the sweeping method, as confirmed in our study, may have influenced these results. Therefore, we expect the sweeping method to play a more important role in these conditions, as accurate detection of *H. pylori* and eradication success is necessary in patients with precancerous conditions. We propose to actively perform RUT with the sweeping method during endoscopy, considering that gastric adenoma and cancer patients undergo endoscopic follow-up. However, further experimental evidence is required in support of our proposal.

This study has a few limitations. First, we did not compare the sweeping method with UBT in a randomized controlled trial. Our study suggests that the sweeping method is a potential alternative to UBT. Randomized controlled trials directly comparing the sweeping method with UBT under various conditions should be conducted, and the

results of such trials could be used to revise the guidelines. Second, this study was not conducted on the general population. Determining the appropriate diagnostic method for *H. pylori* detection in asymptomatic carriers or in primary care settings with limited access to endoscopy will require further research. However, for cases in which endoscopy is already planned, the sweeping method, with its high sensitivity, can replace the conventional tissue sampling method. Additionally, under specific scenarios requiring endoscopy, such as in post-eradication therapy, the sweeping method could be an alternative to UBT. Third, the study conducted a retrospective reanalysis using a dataset originally set up for other comparisons. Fourth, caution is needed when interpreting the results because the study was not conducted exclusively on patients within the UBT gray zone. Therefore, a prospective study targeting a larger number of patients within the gray zone is required. Finally, we were unable to conduct PCR on all swab samples. In future prospective studies, it will be necessary to conduct PCR in all cases.

In conclusion, this study showed that RUT using the sweeping method has higher sensitivity and accuracy than UBT in patients who received *H. pylori* eradication treatment. This method may be a better alternative, especially for patients requiring follow-up endoscopy. Additionally, the sweeping method is expected to demonstrate better diagnostic accuracy, especially in patients under the UBT cutoff values, particularly in the gray zone.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTIONS

Study concept and design: C.K.N. Data acquisition: J.H.K., K.M.L., G.H.L., C.K.N. Data analysis and interpretation: J.M.K., B.P., S.G.L., G.H.L., C.K.N. Drafting of the manuscript: J.H.K., G.H.L., C.K.N. Critical revision of the manuscript for important intellectual content: S.J.S., K.M.L., C.K.N. Statistical analysis: J.M.K., B.P. Obtained funding: C.K.N. Administrative, technical, or material support; study supervision: S.J.S., K.M.L., G.H.L., C.K.N. All authors have read and agreed to the final version of the manuscript.

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DATA AVAILABILITY STATEMENT

The data used or analyzed in this article is available from the corresponding author upon reasonable request.

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