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SpyGlass Direct Visualization System: A Cost-Effective Approach Enhancing Nutritional and Immune Recovery in Difficult Bile Duct Stone Management

Kyung In Shin[1*], Galam Leem[2*], Jungchul Koo[2], Jee Hoon Kim[2], In Rae Cho[3], Jung Hyun Jo[4], Hee Seung Lee[2], Jeong Youp Park[2], Seungmin Bang[2], Seung Woo Park[2], and Moon Jae Chung[2]

[1]Division of Gastroenterology, Department of Internal Medicine, Keimyung University School of Medicine, Daegu;
[2]Division of Gastroenterology, Department of Internal Medicine, Severance Hospital, Yonsei University College of Medicine, Seoul;
[3]Division of Gastroenterology, Department of Internal Medicine, Seoul National University College of Medicine, Seoul;
[4]Division of Gastroenterology, Department of Internal Medicine, Gangnam Severance Hospital, Yonsei University College of Medicine, Seoul, Korea.

Purpose: The SpyGlass DS II Direct Visualization System (SpyDS) is increasingly used as an alternative to percutaneous transhepatic cholangioscopy (PTCS) for difficult bile duct stones (DBDSs). This study compared clinical outcomes, costs, and post-procedural recovery between SpyDS and PTCS.

Materials and Methods: A prospective interventional study was conducted including patients with DBDSs who underwent SpyDS-guided lithotripsy between December 2020 and December 2022. Patients treated with PTCS-guided lithotripsy between July 2018 and July 2020 were used as a comparison group. Primary endpoints were technical success rate and total hospital cost. Secondary endpoints included length of hospital stay, procedure-related cost, adverse events, and markers of recovery, such as nutritional status, immune balance, and skeletal muscle mass.

Results: Forty-three patients were included: 20 patients in the SpyDS group and 23 patients in the PTCS group. Technical success rates were 95.0% for SpyDS and 100% for PTCS. Median total hospital cost was lower in the SpyDS group in univariable analysis (p=0.018), although this difference was not significant after multivariable adjustment. Length of hospital stay was significantly shorter (6.5 days vs. 21.0 days; p<0.001). The SpyDS group showed more favorable early recovery patterns, including higher albumin levels and lower neutrophil-to-lymphocyte ratios at follow-up, as well as less rapid muscle loss.

Conclusion: SpyDS achieved comparable technical success to PTCS and was associated with a markedly shorter hospitalization period. Although adjusted analyses did not show a significant cost difference, the shorter length of stay and favorable recovery trends suggest potential clinical and economic advantages. SpyDS may represent a practical alternative for DBDSs management.
ClinicalTrials.gov trial number: NCT04743089

Key Words: Gallstones, endoscopic retrograde cholangiopancreatography, SpyGlass, single operator cholangioscopy, percutaneous transhepatic cholangioscopy, cost-benefit analysis

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Corresponding author: Moon Jae Chung, MD, PhD, Division of Gastroenterology, Department of Internal Medicine, Severance Hospital, Yonsei University College of Medicine, 50-1 Yonsei-ro, Seodaemun-gu, Seoul 03722, Korea.
E-mail: mjchung@yuhs.ac

*Kyung In Shin and Galam Leem contributed equally to this work.
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INTRODUCTION

Bile duct stones are the most common biliary tract disease. Approximately 90% of bile duct stones can be effectively eliminated using standard techniques such as endoscopic retrograde cholangiopancreatography (ERCP) with a basket catheter, balloon catheter, or mechanical lithotripter, following endoscopic sphincterotomy and/or endoscopic papillary large balloon dilation.[1-3] However, the remaining 10%–15%, referred to as difficult bile duct stones (DBDSs), frequently require additional procedures or specialized devices for successful removal.[4,5] DBDSs include stones of significant size, multiple formations, impacted nature, and those located in the intrahepatic bile ducts or cystic ducts.[3] These stones present technical challenges to conventional devices. Treatment alternatives for DBDSs include Electrohydraulic Lithotripsy (EHL) or Laser Lithotripsy (LL) guided by peroral cholangioscopy, EHL/LL with percutaneous transhepatic cholangioscopy (PTCS) guidance, or surgical stone removal.[1,3,4]

Recently, a new digital cholangioscope, the SpyGlass DS II Direct Visualization System (SpyDS) (Boston Scientific, Marlborough, MA, USA), has gained increasing attention as an effective alternative technique for DBDSs.[3,6,7] This single operator cholangioscopy (SOC) system was developed to overcome the limitations associated with conventional peroral cholangioscopy, including the complexities of installation, relative thickness, and inconvenience of use.[8-10] The SpyDS allows direct access to the bile duct through the working channel of the duodenoscope. With two dedicated irrigation channels and a 1.2-mm working channel, devices such as EHL or LL probes can be inserted and utilized for lithotripsy. It also offers improved image resolution and promises enhanced diagnostic and therapeutic capabilities.[9,11,12]

Although SpyDS and PTCS have traditionally been applied in somewhat different clinical settings, there is a significant overlap in their indications, particularly in the management of DBDSs that are refractory to conventional ERCP.[2,13] In real-world clinical practice, the choice between PTCS and SpyDS is often influenced by institutional resources, operator experience, patient anatomy, and economic considerations.[14] Furthermore, PTCS continues to be widely used due to the relatively high cost and limited availability of SOC systems, as well as the learning curve associated with their use. Although the PTCS procedure itself can be straightforward and effective because it directly approaches the DBDSs, it requires assessment, dilatation, and maturation of the percutaneous transhepatic route. This has the significant disadvantage of prolonging the patient's hospitalization and exposing them to repeated painful procedures, which can lead to a longer recovery period after completion of the procedure. Although the cost of a single procedure is lower than that of the SOC system, the overall cost of longer hospitalizations and repeated transhepatic route dilation procedures can be greater than that of the SOC system.

We designed this prospective interventional study to investigate the cost, effectiveness, and safety of the SpyDS in treating patients with DBDSs compared with conventional PTCS. We aimed to compare length of hospital stay and the overall cost burden associated with the procedures in patients who had their DBDS removed using these two techniques. Additionally, we assessed the patients' time to return to daily life by evaluating their nutritional status, immune system balance, and degree of muscle mass recovery before and after the procedure.

MATERIALS AND METHODS

Trial design

This prospective interventional study was approved by the Institutional Review Board of Yonsei University Medical Center (number 4-2018-0031). Patients were recruited at the Yonsei University Severance Hospital (Seoul, Korea) between December 2020 and December 2022. Patients aged >19 years with DBDSs that could not be removed using conventional ERCP were eligible for inclusion. DBDSs were defined according to objective criteria commonly cited in the literature, including one or more of the following: stone size ≥15–20 mm, multiple stones, impacted stones, unusual stone shape (e.g., barrel-shaped), atypical location (e.g., intrahepatic or cystic ducts), or anatomical factors such as a narrow or sharply angulated bile duct that hinders standard ERCP-based extraction.[2,3] These features were assessed based on imaging findings and intra-procedural evaluation. Patients were ineligible if the stones were located in the peripheral bile duct beyond the reach of the SpyDS or if the peroral duodenoscope could not access the ampulla of Vater due to anatomical deformities from surgeries, such as total gastrectomy. The patients who underwent PTCS-guided lithotripsy for DBDSs at the same hospital between July 2018 and July 2020 were allocated to the control group. After the procedure, recurrence within 6 months was defined as incomplete removal, whereas any recurrence occurring after 6 months was considered a separate event.[15,16]

Study population

Among 23 patients initially assessed for inclusion in the SpyDS group, three were excluded due to failed cannulation (n=1), spontaneous stone passage prior to the procedure (n=1), and withdrawal of consent (n=1). As a result, 20 patients were included in the final SpyDS group.

For the PTCS group, a total of 74 cases who underwent PTCS-guided lithotripsy during the study period were screened. Of these, 51 were excluded for the following reasons: concurrent intrahepatic duct stones (n=16), surgically altered anatomy such as Roux-en-Y or total gastrectomy (n=34), and loss to follow-up before outcome assessment (n=1). Ultimately, 23 patients were included in the PTCS group.

Patient enrollment and reasons for exclusion are summa-

rized in Fig. 1.

Procedures

In the SpyDS group, after successful selective cannulation of the bile duct, the SpyDS was inserted into the common bile duct to directly visualize the DBDSs. After stone fragmentation using EHL/LL under SpyDS guidance, the fragmented stones were retrieved using standard devices, such as a basket or balloon catheter.

In the PTCS group, the bile duct was accessed using an 8.5F drainage catheter inserted into either the left or right hepatic duct. Sequential tract dilation was then performed over two to three sessions at intervals of 2 to 3 days, reaching up to 18F. PTCS was performed using an 18F access sheath and a flexible videoscope (CYF-240A; Olympus, Tokyo, Japan) with an outer diameter of 5.9 mm and a 2.0-mm working channel. After stone fragmentation through PTCS-guided EHL/LL, they were removed by pushing the scope directly through the ampulla of Vater or by extracting the stones using a basket.

Representative fluoroscopic images of SpyDS- and PTCS-guided lithotripsy are shown in Fig. 2.

Experts with experience in conducting more than 3000 ERCP procedures served as operators for all endoscopic procedures, whether it was using SpyDS or PTCS. Complete stone removal was confirmed using a cholangiogram. If the stones were not entirely removed during the initial session, a temporary biliary stent or percutaneous transhepatic biliary drainage catheter was placed to prevent biliary obstruction, and endoscopic procedures were repeated until complete removal was achieved. All patients were hospitalized for at least 24 hours after endoscopic treatment to monitor adverse events. Conscious sedation with standard doses of propofol and midazolam was used equally in both groups.

Outcome measures

The primary endpoints were the technical success rate and total hospital cost. Technical success was defined as complete clearance of all biliary stones from the common bile duct, re-

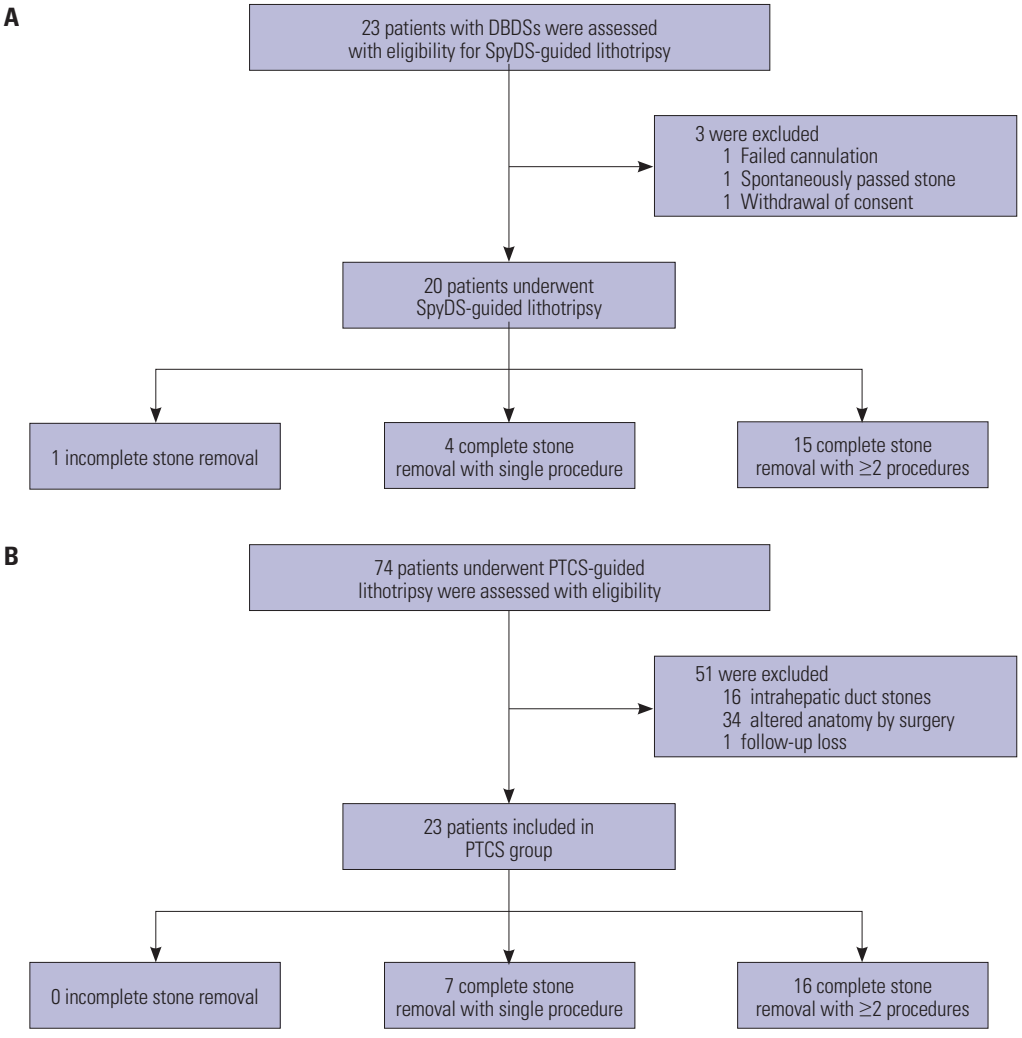

Fig. 1. Study profile. Summarized flow of enrollment of the participants, reasons for exclusion, and results of stone removal for (A) SpyDS and (B) PTCS. DBDS, difficult bile duct stone; SpyDS, SpyGlass DS II Direct Visualization System; PTCS, percutaneous transhepatic cholangioscopy.

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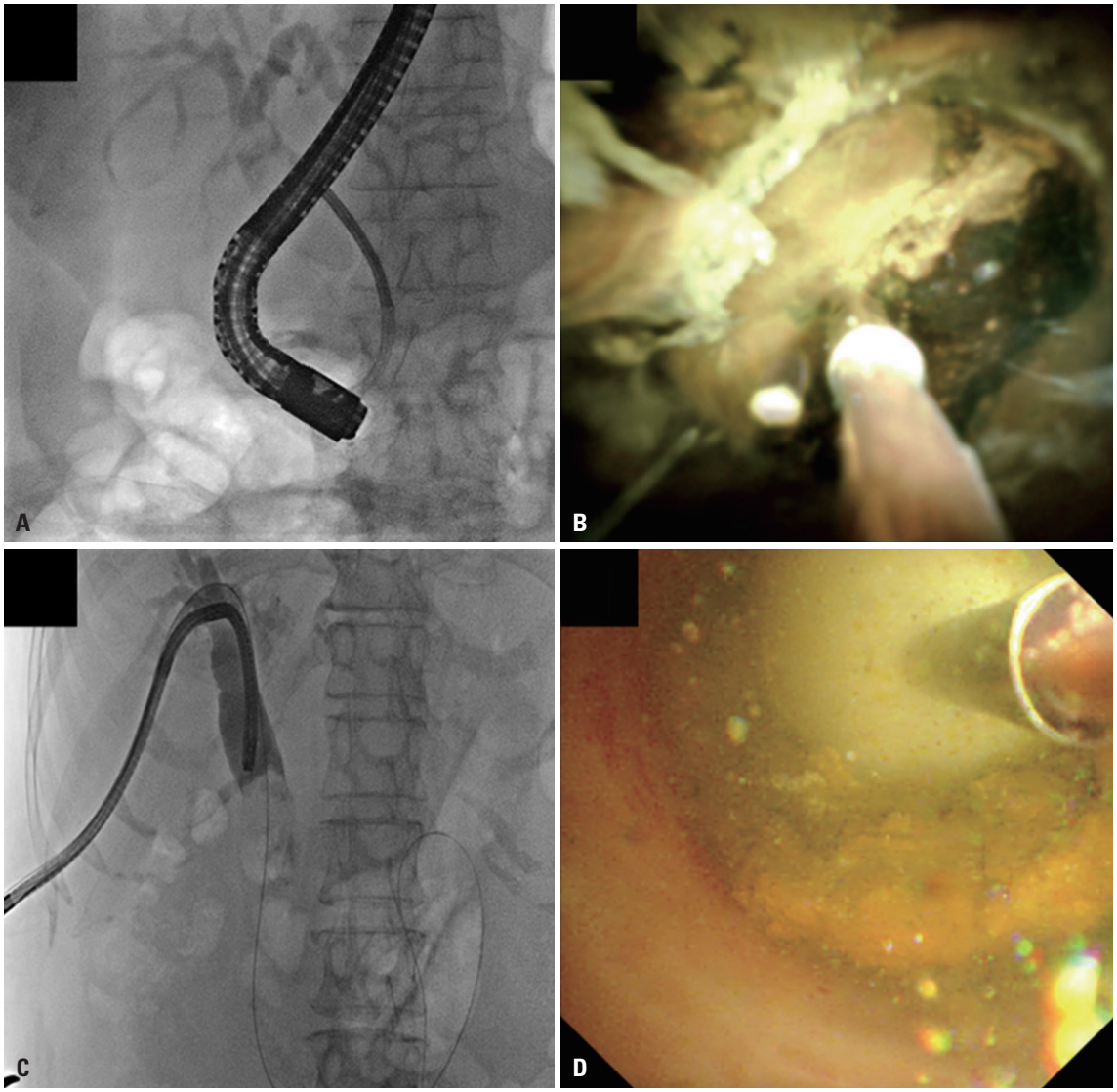

Fig. 2. Representative images of the SpyDS-guided lithotripsy (A and B) and the PTCS-guided lithotripsy (C and D). A and C are fluoroscopic images and B and D are visual cholangioscope images. SpyDS, SpyGlass DS II Direct Visualization System; PTCS, percutaneous transhepatic cholangioscopy.

gardless of the number of sessions required.[17] The total hospital cost was defined as the comprehensive sum of all expenses incurred from admission to discharge, encompassing all costs associated with procedures, tests, medications, inpatient rooms, and any other relevant healthcare-related costs during hospitalization. If, after discharge, additional procedures such as removal of a plastic stent or cholangiography were performed in an outpatient setting to complete the stone removal procedure, these costs were also included. All costs were derived from actual claims recorded in the hospital's electronic billing system. Itemized cost data were not prospectively collected, but representative device and procedural cost items are summarized in Supplementary Table 1 (only online). For transparency and comparability, these representative unit costs were indexed to the 2021 Korean National Health Insurance reimbursement schedule—the year in which SpyDS reimbursement was introduced. This reference-year standardization was used solely for reporting unit costs in the Supplementary Table 1 (only online) and did not alter the original cost values used in the statistical analyses.

Secondary endpoints included the total length of hospital stay, procedure-related costs, and adverse events. Procedure-related cost was defined as the sum of all direct expenses incurred during the lithotripsy procedure, including device costs and procedural charges, excluding hospitalization and medication costs. Adverse events were defined according to the ASGE guidelines, including procedure-related complications such as cholangitis, pancreatitis, bleeding, perforation, and sepsis.[18] Additionally, we analyzed the length of hospital stay after the first procedure and total procedure time. The total procedure time was defined as the sum of all durations from the initial SpyDS and PTCS procedures to the last endoscopic procedure

in each group.

We additionally evaluated recovery metrics after the procedure using serum albumin and neutrophil-to-lymphocyte ratio (NLR) levels. Considering that the NLR in the peripheral blood reflects the balance of the systemic immune system, we considered an NLR value higher than 3.0 or below 0.7 to be pathological.[19] Nutritional recovery was defined by restoration of serum albumin toward baseline levels, while immune balance was assessed by normalization of NLR. Measurements were taken at three standardized time points: on admission, at hospital discharge, and at the first outpatient visit approximately 14 days after discharge.

Evaluation of changes in skeletal muscle index

To assess the time to return to daily life after the procedure, we calculated the T9-L3 skeletal muscle index (SMI) of patients from CT scans taken before and after the procedure and analyzed the changes. Among the enrolled patients, those who underwent at least two CT scans, including an initial scan and a follow-up CT scan, within 180 days were included in this analysis. We performed volume segmentation of the CT scans using the three-dimensional (3D) segmentation model in TotalSegmentator v.2.0.4[20] and calculated T9-L3 SMI using the following formula:

$$(\text{T9-L3 SMI}) = 1.04 \times 0.001 \times \frac{\text{T9-L3 Muscle Mass}}{\text{Height}^2}$$

We then derived the T9-L3 indexes over 180 days using Piecewise Cubic Hermite Interpolating Polynomial interpolation (PCHIP) to account for variability in CT scan timing across patients.[21] We classified the patients into three classes: class 0, cases with convexly decreasing SMI in the first 60 days; class 1, cases with concavely decreasing SMI in the first 60 days; and class 2, cases with increasing or stable SMI after the first 60 days. Classes were assigned based on longer consecutive tendencies of the second-derivative function.

Statistical analysis

Data from patients treated with SpyDS were prospectively collected and compared with retrospective data from patients treated with PTCS. Continuous variables were tested for normal distribution using the D'Agostino–Pearson normality test and were analyzed using either an independent-samples t-test or the Mann–Whitney U test for between-group comparisons, and the Wilcoxon signed-rank test for paired within-group comparisons. For categorical variables, we used either Fisher's exact test or the chi-square test according to the expected frequency of each cell for statistical analysis. Total length of hospital stay was analyzed using negative binomial regression after confirming overdispersion in the Poisson model (Pearson χ^2/df >1). Procedure-related and total hospital costs were modeled using generalized linear models with a Gamma distribution and log link. Effect estimates were reported as incidence rate ratios (IRRs) or ratios of mean costs (exp[β]) with 95% confidence intervals (CIs). All models were adjusted for clinical covariates. Repeated laboratory markers were analyzed using linear mixed-effects models. Time was modeled as a categorical factor because exact calendar dates for follow-up labs were not consistently available in the retrospective dataset. Albumin was analyzed on its original scale, whereas NLR was log-transformed due to substantial right-skewness. Estimated marginal means and contrast-based 95% CIs were derived to compare groups at each time point. Technical success and total hospital cost were prespecified as the two primary outcomes of the study. All other outcomes, including length of stay, procedure-related cost, adverse events, and recovery markers, were considered secondary and exploratory outcomes. Analyses of secondary outcomes were interpreted cautiously in the context of multiple comparisons. All statistical analyses were conducted using either the statistical software R (version 4.5.1; R Foundation for Statistical Computing, Vienna, Austria) or Prism software V.8.4.3 (GraphPad, La Jolla, CA, USA). Statistical significance was set at $p<0.05$.

RESULTS

Patient characteristics

A total of 20 cases in the SpyDS group and 23 in the PTCS group

Table 1. Patient Characteristics

Variables	SpyDS group (n=20)	PTCS group (n=23)	*p*
Age (yr)	70.3±13.3	73.9±11.1	0.344
Sex			0.639
Male	9 (45.0)	12 (52.2)	
Female	11 (55.0)	11 (47.8)	
Comorbidities			
Hypertension	8 (40.0)	7 (30.4)	0.540
Diabetes mellitus	4 (20.0)	1 (4.3)	0.167
Cerebrovascular disease	2 (10.0)	6 (26.1)	0.250
Heart disease	4 (20.0)	1 (4.3)	0.167
Chronic kidney disease	2 (10.0)	0 (0.0)	0.210
Respiratory disease	1 (5.0)	3 (13.0)	0.611
Prior abdominal surgery	5 (25.0)	8 (24.8)	0.526
Prior history of ERCP	5 (25.0)	4 (17.4)	0.711
Characteristics of bile duct stones			
Number			0.187
Single	7 (35.0)	4 (17.4)	
Multiple	13 (65.0)	19 (82.6)	
Size*	18.3±5.8	15.3±4.6	0.068

SpyDS, SpyGlass DS II Direct Visualization System; PTCS, percutaneous transhepatic cholangioscopy; ERCP, endoscopic retrograde cholangiopancreatography.
Data are presented as n (%) or mean±standard deviation.
*The largest stone size was indicated if there were multiple stones.

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were included in the final analysis (Fig. 1). Baseline characteristics of the two groups are presented in Table 1. There were no statistically significant differences between the groups in terms of age, sex, or major comorbidities, including hypertension, diabetes mellitus, cerebrovascular disease, or heart disease. In addition, there were no significant differences in prior history of abdominal surgery or ERCP. Stone characteristics, including number (single vs. multiple) and size, were also comparable between groups.

Primary outcomes

The technical success rate of DBDSs removal was 95.0% (19 of 20) in the SpyDS group and 100% (23 of 23) in the PTCS group. There was no significant difference in the required number of endoscopic procedures for complete stone removal (mean number of endoscopic procedures, 2.3 and 2.0, respectively; p=0.289). The total hospital cost was significantly lower in the SpyDS group than in the PTCS group (median 9302062 KRW in the SpyDS group and 13928054 KRW in the PTCS group; p=0.018) (Table 2).

Table 2. Clinical Outcomes

Variables	SpyDS group (n=20)	PTCS group (n=23)	p
Primary outcomes			
Technical success rate	19 (95.0)	23 (100)	0.278
Total hospital cost (KRW)	9302062 [8556562–10937220]	13928054 [11743975–16512978]	0.018*
Secondary outcomes			
Length of hospital stay (days)	6.5 [5.0–16.0]	21.0 [16.0–27.0]	<0.001***
Procedure-related cost (KRW)	5863130 [4218240–6555679]	3999428 [3438195–4900954]	0.002**
Adverse events	4 (20.0)	3 (13.0)	0.687
Cholangitis	3 (15.0)	2 (8.7)	
Pancreatitis	0 (0.0)	0 (0.0)	
Bleeding	0 (0.0)	1 (4.3)	
Wire impaction	1 (5.0)	0 (0.0)	
Other outcomes			
Total procedure times (min)	50.5 [38.75–60.5]	58.0 [28.0–77.0]	0.859
Length of stay after 1st procedure (days)	3.5 [2.0–8.75]	21.0 [15.0–24.0]	0.006**
Required number of endoscopic procedures for complete stone removal	2.3±1.2	2.0±0.8	0.289

SpyDS, SpyGlass DS II Direct Visualization System; PTCS, percutaneous transhepatic cholangioscopy.
Data are presented as n (%), mean±standard deviation, or median [IQR].
*p<0.05; **p<0.01; ***p<0.001.

Table 3. Multivariate Regression Analysis for Clinical Outcomes

Variables	Length of hospital stay		Total hospital cost		Procedure-related cost	
	IRR (95% CI)	p	Ratio (95% CI)	p	Ratio (95% CI)	p
SpyDS (ref. PTCS)	0.36 (0.25–0.51)	<0.001***	1.06 (0.69–1.63)	0.770	1.35 (1.11–1.67)	0.002**
Age	1.00 (0.98–1.02)	0.995	1.00 (0.99–1.01)	0.757	1.00 (0.99–1.01)	0.870
Hypertension	1.00 (0.68–1.47)	0.998	0.91 (0.55–1.50)	0.589	1.15 (0.68–1.95)	0.327
Diabetes mellitus	0.81 (0.52–1.38)	0.504	0.78 (0.44–1.38)	0.287	1.20 (0.76–2.03)	0.077
Cerebrovascular disease	0.87 (0.39–1.47)	0.690	0.78 (0.44–1.38)	0.609	0.81 (0.47–1.40)	0.528
Heart disease	0.76 (0.39–1.44)	0.375	0.72 (0.40–1.29)	0.940	0.67 (0.38–1.16)	0.362
Chronic kidney disease	1.03 (0.53–2.03)	0.223	1.23 (0.77–1.95)	0.596	1.26 (0.81–2.00)	0.223
Respiratory disease	0.93 (0.36–2.91)	0.829	0.85 (0.39–1.89)	0.594	1.05 (0.59–1.74)	0.927
Prior abdominal surgery	1.00 (0.33–3.05)	0.995	0.82 (0.33–1.99)	0.551	1.43 (0.95–3.10)	0.929
Prior history of ERCP	0.82 (0.59–1.16)	0.135	1.02 (0.72–1.45)	0.965	0.56 (0.30–1.12)	0.271
Number of stone	1.11 (0.95–1.25)	0.267	0.99 (0.83–1.17)	0.215	0.88 (0.73–1.15)	0.807
Size of stone	1.03 (0.99–1.06)	0.104	1.01 (0.99–1.03)	0.163	1.39 (1.05–2.21)	0.005**
Cholangitis severity	1.37 (1.10–1.70)	0.003**	1.31 (0.97–1.87)	0.080	0.69 (0.30–1.36)	0.351

IRR, incidence rate ratios; CI, confidence interval; SpyDS, SpyGlass DS II Direct Visualization System; PTCS, percutaneous transhepatic cholangioscopy; ERCP, endoscopic retrograde cholangiopancreatography.
Reference categories: all comorbidities: No, previous abdominal surgery/previous ERCP/multiple stones; No, stone size, continuous variable (per mm); cholangitis severity, grade I.
**p<0.01; ***p<0.001.

However, in the Gamma generalized linear model (Table 3), the SpyDS group was not significantly associated with total hospital cost after covariate adjustment (ratio of mean cost 1.06; 95% CI 0.69–1.63; p=0.770).

Secondary outcomes

Total length of hospital stay was significantly shorter in the SpyDS group than in the PTCS group (median 6.5 days vs. 21.0 days; p<0.001). This finding remained consistent when analyzing length of hospital stay after the first procedure (median 3.5 days vs. 21.0 days; p=0.006) (Table 2).

Negative binomial regression demonstrated that the SpyDS group was significantly associated with shorter length of hospital stay (IRR 0.36; 95% CI 0.25–0.51; p<0.001), independent of comorbidities, cholangitis severity, and other confounders (Table 3).

Procedure-related costs were higher in the SpyDS group, and this difference remained significant in multivariable Gamma generalized linear model modeling (ratio 1.35; 95% CI 1.11–1.67; p=0.0016). Stone size was also an independent predictor of higher procedure-related cost (p=0.0046).

Recovery of nutritional status, balance of immune system, and skeletal muscle mass

To evaluate recovery following the procedure, we assessed changes in nutritional status, immune system balance, and skeletal muscle mass at three standardized time points (admission, discharge, and the first outpatient visit). Serum albumin decreased during hospitalization in both groups and returned toward baseline by the first outpatient visit. In the mixed-effects model, no significant between-group differences were observed at admission or discharge; however, albumin was significantly higher in the SpyDS group at the first outpatient visit (estimate +0.393 g/dL; 95% CI +0.090 to +0.696; p=0.012), indi-

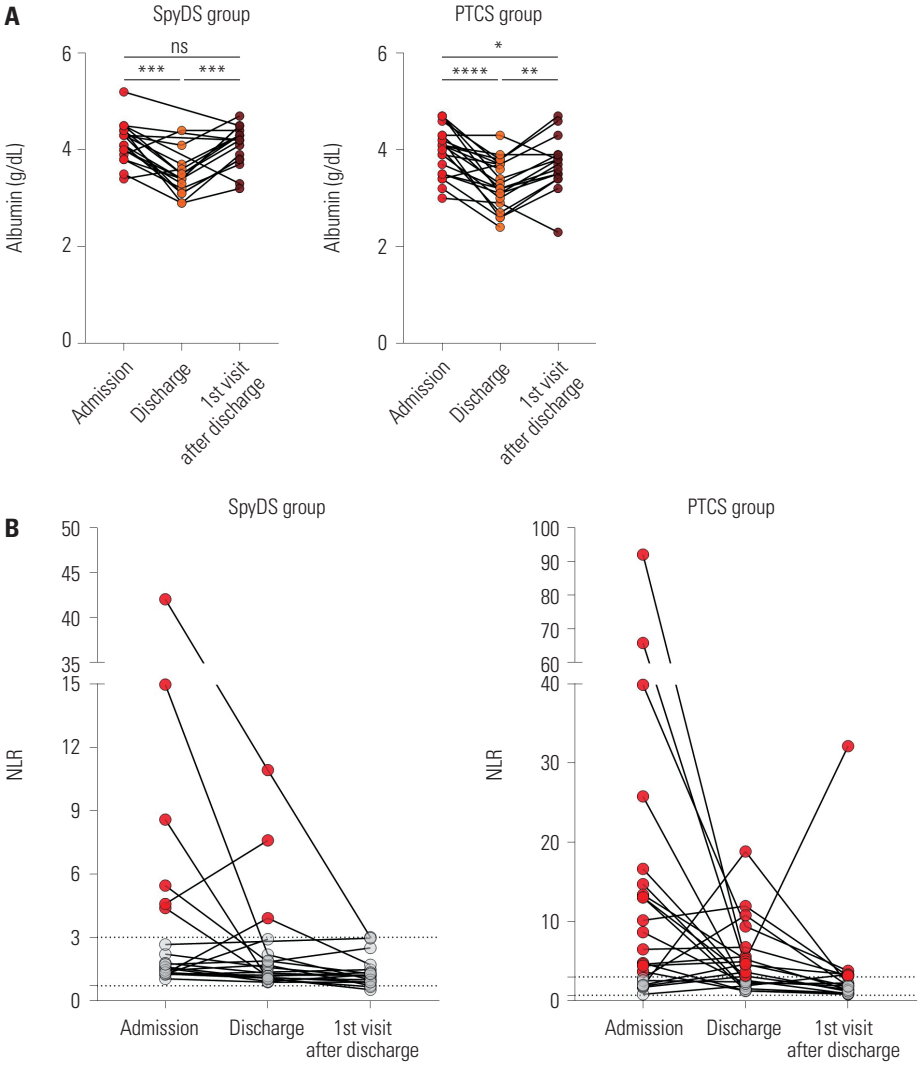

Fig. 3. Changes in albumin levels and NLRs from admission to 1st visit after discharge. (A) Changes in albumin levels in the SpyDS group and the PTCS group. (B) Changes in NLRs in the SpyDS group and the PTCS group: gray dots for NLR values within the normal range and red dots for NLR values outside the normal range. The normal range for NLR values was from 0.7 to 3.0. *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001. ns, not significant; NLR, neutrophil-to-lymphocyte ratio; SpyDS, SpyGlass DS II Direct Visualization System; PTCS, percutaneous transhepatic cholangioscopy.

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cating a more favorable nutritional recovery profile compared with PTCS (Fig. 3A and Table 4).

Since the NLR reflects systemic inflammatory balance and demonstrated substantial right-skewness, log-transformed NLR values were analyzed using a linear mixed-effects model. The SpyDS group exhibited significantly lower log-NLR values at admission (estimate -0.996; $p<0.001$) and at discharge (estimate -0.668; $p=0.019$), with a nonsignificant trend toward lower values at the first outpatient visit (estimate -0.488; $p=0.091$). These findings suggest a trend toward earlier normalization of systemic inflammatory markers in the SpyDS group (Fig. 3B and Table 4).

Table 4. Recovery of Nutritional Status and Balance of Immune System

Variables	SpyDS-PTCS (estimate)	95% CI	*p*
Albumin level (g/dL)			
Admission	0.270	-0.072 to 0.486	0.148
Discharge	0.161	-0.142 to 0.465	0.290
First visit after discharge†	0.393	0.090 to 0.696	0.012*
Log-NLR			
Admission	-0.996	-1.514 to -0.478	<0.001***
Discharge	-0.668	-1.221 to -0.115	0.019*
First visit after discharge†	-0.488	-1.056 to 0.081	0.091

SpyDS, SpyGlass DS II Direct Visualization System; PTCS, percutaneous transhepatic cholangioscopy; CI, confidence interval; NLR; neutrophil-to-lymphocyte ratio.
*$p<0.05$; ***$p<0.001$; †Patients visited the outpatient clinic 10 to 14 days after discharge.

Finally, we calculated the T9-L3 SMI from CT scans to assess the recovery of skeletal muscle mass after the procedure. Fifteen patients from the SpyDS group and nine patients from the PTCS group underwent at least two CT scans, including an initial scan and a follow-up CT scan within 180 days, and were included in the analysis. We found that the proportion of class 1 patients with rapid muscle wasting was higher in the PTCS group (22.2% in the PTCS group and 13.3% in the SpyDS group), suggesting that a longer hospitalization period with repeated procedures in the PTCS group resulted in the rapid wasting of skeletal muscle mass (Fig. 4).

Adverse events

No serious procedure-related adverse events were observed in either group. Adverse events related to the procedures occurred

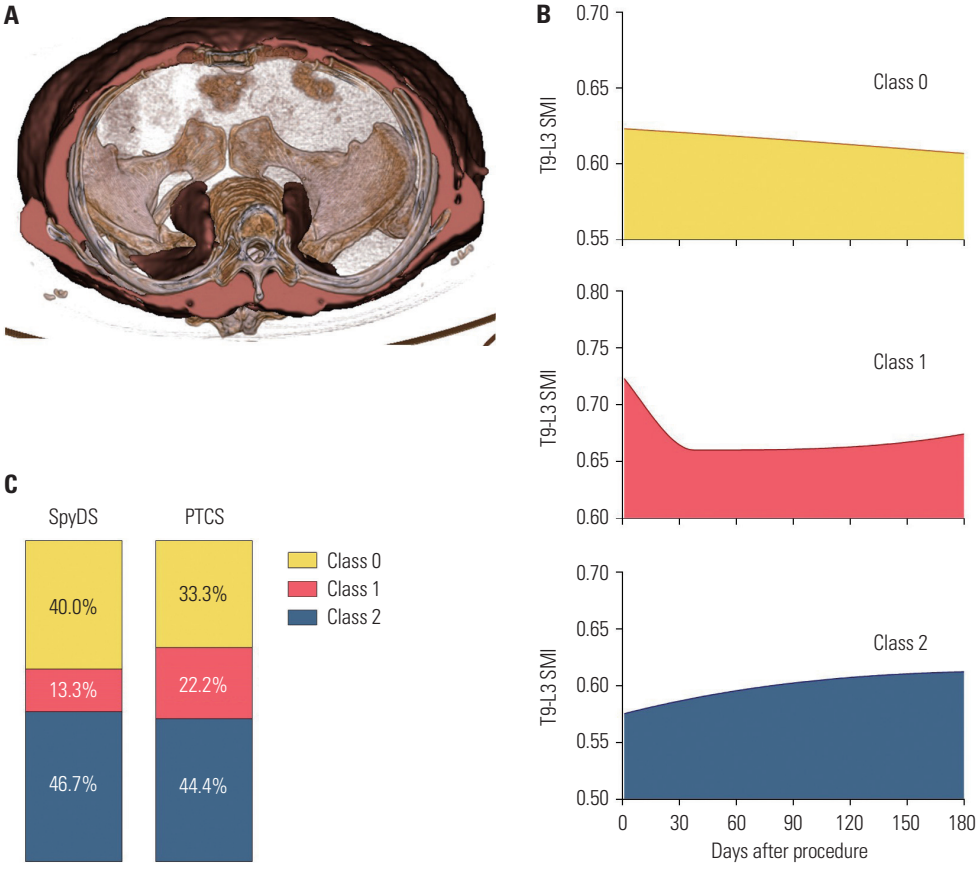

Fig. 4. Skeletal muscle mass change within 6 months after the procedure. (A) Representative image of skeletal muscle volume segmentation from the CT scans using three-dimensional Slicer image computing platform. Red area represents the muscle and beige area represents the skeleton. (B) Representative T9-L3 SMI curve for class 0, 1, and 2: class 0 for cases with convexly decreasing SMI in the first 60 days; class 1 for cases with concavely decreasing SMI in the first 60 days; and class 2 for cases with increasing or stable SMI after the first 60 days. (C) Proportion of class 0, 1, and 2 in the SpyDS group and in the PTCS group. SpyDS, SpyGlass DS II Direct Visualization System; PTCS, percutaneous transhepatic cholangioscopy; SMI, skeletal muscle index.

in four patients in the SpyDS group and three patients in the PTCS group. In the SpyDS group, there were three cases of cholangitis and one case of wire impaction, whereas in the PTCS group, there were two cases of cholangitis and one case of bleeding. All adverse events, except wire incarceration, were successfully resolved with conservative treatment. In the case of wire incarceration, surgical intervention was required.

DISCUSSION

To the best of our knowledge, this is the first study to compare the clinical and economic outcomes of SpyDS- and PTCS-guided lithotripsy for the treatment of DBDSs. There were no significant differences in technical success rate, number of endoscopic procedures required, or incidence of adverse events between the groups. The most notable difference between the two approaches was the length of hospital stay. Patients treated with SpyDS experienced a markedly shorter length of stay, a finding that remained robust after adjustment for clinical covariates in negative binomial regression. As inpatient resource use accounted for a substantial proportion of overall medical expenditure in our cohort, this reduction in hospitalization likely contributed to the lower unadjusted total hospital cost observed in the SpyDS group. However, the cost difference no longer reached significance after multivariable Gamma generalized linear model analysis, suggesting that the apparent cost advantage of SpyDS was primarily mediated through its impact on hospitalization rather than a direct reduction in procedural or ancillary costs. Procedure-related expenses were higher in the SpyDS group, reflecting the intrinsic cost of single-operator cholangioscopy equipment and devices. Nonetheless, when considered alongside the considerably shorter hospital stay, the overall economic profile of SpyDS may still be favorable in selected clinical settings, particularly where inpatient care constitutes the dominant component of total cost.

Beyond cost and hospitalization metrics, SpyDS-treated patients showed more favorable short-term recovery patterns. Albumin levels returned toward baseline more rapidly, and NLR values demonstrated a trend toward earlier normalization following discharge. Although these findings did not reach statistical significance for all comparisons, they consistently suggested an earlier resolution of peri-procedural physiological stress in the SpyDS group. In addition, the proportion of patients showing rapid muscle wasting appeared lower in the SpyDS group compared to the PTCS group. This trend, along with more favorable patterns in nutritional and immune markers, may indicate a potentially faster recovery trajectory in the SpyDS group, which could contribute to an earlier return to daily activities. Taken together, these results indicate that SpyDS achieves clinical effectiveness comparable to PTCS while potentially facilitating a faster return to baseline physiological status. Although definitive cost-saving effects could not be established after multivariable adjustment, the combination of shorter hospitalization, favorable recovery trends, and comparable safety outcomes supports the role of SpyDS as a practical and patient-centered alternative for the management of DBDSs.

PTCS continues to be widely utilized for the diagnosis and treatment of biliary diseases, maintaining its unique role. Patients with complicated cholelithiasis or those who have experienced ERCP failure are considered suitable candidates for bile duct stone removal using PTCS. In particular, PTCS may be prioritized in cases involving intrahepatic duct stones or those with altered anatomy.[3,22-24] However, PTCS typically requires a hospitalization period of at least 14 days for hepatocutaneous fistula formation, tract dilation, and tract epithelial maturation prior to the endoscopic procedure. This not only induces pain related to fistula formation in patients but also imposes a significant economic burden.[25] In this regard, the removal of bile duct stones using SpyDS may be advantageous.

Several studies have reported on the successful management of challenging bile duct stones using SOC-guided EHL.[7,26,27] Jin, et al.[28] conducted a recent systematic review and meta-analysis of 24 studies, revealing a 94% rate of complete stone clearance (95% CI, 90.2%–97.5%) and a 71.1% rate of single-session stone clearance (95% CI, 62.1%–79.5%). The average number of sessions required for complete stone clearance was 1.26 (95% CI, 1.17%–1.34%). When assessing the necessary endoscopic sessions to achieve complete stone removal, we factored into the sessions dedicated to removing a plastic stent via ERCP to ensure accurate cost evaluation. This contributed to a relatively higher number of sessions compared to the total number of endoscopy sessions, as suggested in previous studies on SOC-guided EHL.

Nevertheless, despite these advantages, SpyDS has certain limitations that should be acknowledged. Its use can be technically challenging or limited in patients with surgically altered anatomy (e.g., Roux-en-Y reconstruction) or severe biliary strictures, which may restrict scope access and maneuverability. Furthermore, the smaller channel size and scope diameter compared to traditional cholangioscopy systems can limit irrigation and device insertion in some cases.[2] Therefore, while SpyDS offers significant benefits, careful case selection remains vital to optimize outcomes and manage anatomical or technical constraints effectively.

As DBDS is not a malignant disease, returning to daily life after treatment is a very important issue for patients. However, due to repeated procedures, repeated fasting before procedures, and adverse events such as infections, dyspepsia, and pain associated with DBDSs and the procedures, patients' nutritional status, immune system balance, and muscle mass inevitably decrease. Trends in nutritional status, immune balance, and muscle mass recovery may provide indirect insight into how quickly a patient can return to daily life, although these markers can be influenced by various external factors. In this study, we found that the use of SpyDS to remove DBDSs resulted in faster normalization of albumin levels and NLR values than the use of PTCS. Ad-

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ditionally, the frequency of rapid muscle wasting was lower in the SpyDS group. These findings suggest that SpyDS may not only be associated with shorter hospitalization, but also with a more favorable short-term recovery profile, potentially contributing to a faster return to daily activities compared to PTCS. Sarcopenia assessments using CT to measure skeletal muscle mass have been conducted in numerous previous studies. Currently, determining the SMI at the L3 level is regarded as the gold standard.[29] However, recent reports suggest that 3D volumetric body images provide a more accurate reflection of actual body composition than traditional two-dimensional cross-sectional images at the L3 level.[30,31] Consequently, we also utilized the muscle volume from T9 to L3 for evaluation in our study. This PCHIP-based interpolation approach was employed to visualize individual muscle recovery trends in an exploratory manner. While it accommodates variability in imaging intervals, the method remains descriptive and unvalidated against clinical outcome thresholds; thus, interpretations should be considered preliminary and hypothesis-generating.

Cholangitis is the most common adverse event observed in cholangioscopy-guided EHL for DBDSs. This was attributed to the increased biliary pressure caused by the frequent saline irrigation of the bile duct during the procedures, and our study findings align with this pattern.[28,32] In our study, the overall adverse event rate for the SpyDS group was 20%, which was higher than the rates described in previous studies (up to 14%). This discrepancy may be due to the extended endoscopic procedure time, potentially influenced by variations in skill level attributed to the recent introduction of SOC, as well as the low stone destruction power of EHL. In previous comparative analyses, laser lithotripsy demonstrated higher complete stone clearance rates than electrohydraulic lithotripsy (LL 91%–95% vs. EHL 76%–88%).[33] However, due to the limited availability and regulatory constraints of LL in Korea during the study period, only one patient underwent LL in our cohort, precluding within-group comparison.

Our study supports the benefits of SpyDS; however, it has some limitations. First, this study was conducted on a small number of patients from a single center. While significant differences were found in key outcomes such as hospital stay and cost, the small sample size may have limited the ability to detect differences in less frequent events. Validation in larger cohorts is warranted. Second, the enrollment period of the patients differed. This non-contemporaneous design may have introduced selection bias due to potential differences in baseline patient characteristics or changes in hospital cost structures. In particular, the SpyDS group was treated during the COVID-19 pandemic, which could have affected hospitalization or discharge practices. Although pandemic-related factors were difficult to quantify, we performed multivariable regression analysis adjusting for key clinical confounders for baseline differences. All patients were treated at the same tertiary referral center, where cost estimation and billing protocols remained consistent during the study period. Although reimbursement schedules under the Korean National Health Insurance system are periodically updated, annual adjustments during the study window were relatively small. Therefore, potential differences in unit costs between the two enrollment periods are unlikely to have materially influenced the primary cost comparisons. Finally, the subgroup analyses on nutritional and immune recovery were exploratory in nature and included a limited number of patients, which reduced statistical power and precluded formal comparisons between groups. However, these analyses were meaningful in suggesting overall recovery trends across groups.

In conclusion, this study suggests that SpyDS-guided lithotripsy may serve as a practical alternative for the management of DBDSs. SpyDS was associated with a markedly shorter length of hospital stay and comparable technical success, and demonstrated favorable trends in early recovery markers, including albumin and NLR. Although the adjusted total hospital cost did not differ significantly between groups, the reduction in hospitalization duration indicates a potential system-level economic benefit. These findings should be interpreted in light of the non-contemporaneous control group and single-center design. Larger multicenter studies are warranted to validate these observations and to refine patient selection criteria.

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AUTHOR CONTRIBUTIONS

Conceptualization: Galam Leem, In Rae Cho, Jung Hyun Jo, Hee Seung Lee, Jeong Youp Park, Seungmin Bang, Seung Woo Park, and Moon Jae Chung. Data curation: Kyung In Shin and Galam Leem. Formal analysis: Kyung In Shin, Galam Leem, and Jungchul Koo. Funding acquisition: Moon Jae Chung. Investigation: Galam Leem, In Rae Cho, Jung Hyun Jo, Hee Seung Lee, Jeong Youp Park, Seungmin Bang, Seung Woo Park, and Moon Jae Chung. Methodology: Galam Leem and Moon Jae Chung. Project administration: Moon Jae Chung. Resources: Galam Leem, In Rae Cho, Jung Hyun Jo, Hee Seung Lee, Jeong Youp Park, Seungmin Bang, Seung Woo Park, and Moon Jae Chung. Software: Kyung In Shin. Supervision: Moon Jae Chung. Validation: Kyung In Shin and Galam Leem. Visualization: Kyung In Shin. Writing—original draft: Kyung In Shin. Writing—review & editing: all authors. Approval of final manuscript: all authors.

ORCID iDs

Kyung In Shin https://orcid.org/0000-0001-9311-8160
Galam Leem https://orcid.org/0000-0001-6490-0911
Jungchul Koo https://orcid.org/0009-0000-1169-8043
Jee Hoon Kim https://orcid.org/0009-0003-1323-7728
In Rae Cho https://orcid.org/0000-0001-9874-5526
Jung Hyun Jo https://orcid.org/0000-0002-2641-8873
Hee Seung Lee https://orcid.org/0000-0002-2825-3160
Jeong Youp Park https://orcid.org/0000-0003-0110-8606

Seungmin Bang https://orcid.org/0000-0001-5209-8351
Seung Woo Park https://orcid.org/0000-0001-8230-964X
Moon Jae Chung https://orcid.org/0000-0002-5920-8549

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