Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.JournalofSurgicalResearch.com

Efficacy of Xenon Light With Indocyanine Green for Intersegmental Visibility in Thoracoscopic Segmentectomy

Takuya Matsui, MD,[a,b] *Yusuke Takahashi, MD, PhD,*[a] *Takeo Nakada, MD, PhD,*[a] *Hirokazu Matsushita, MD, PhD,*[b] *Yuko Oya, MD,*[a,c] *Noriaki Sakakura, MD, PhD,*[a] *and Hiroaki Kuroda, MD, PhD*[a,*]

[a] *Department of Thoracic Surgery, Aichi Cancer Center Hospital, Nagoya, Japan*
[b] *Division of Translational Oncoimmunology, Aichi Cancer Center Research Institute, Nagoya, Japan*
[c] *Department of Thoracic Oncology, Aichi Cancer Center Hospital, Nagoya, Japan*

ARTICLE INFO

Article history:
Received 12 April 2020
Received in revised form
2 October 2020
Accepted 1 November 2020
Available online xxx

Keywords:
Segmentectomy
Indocyanine green
Thoracoscopic surgery
Intersegmental boundary line
Xenon

ABSTRACT

Background: We previously reported useful methods that can be implemented to identify intersegmental boundary lines (IBLs) by using an intravenous indocyanine green (ICG) fluorescence imaging system (ICG-FS) during a thoracoscopic anatomical segmentectomy (TAS). The aim of this study was to evaluate the recently released third-generation ICG-FS that features an emphasizing xenon-light source for IBL identification.

Methods: We prospectively studied cases involving 106 consecutive patients who underwent TAS. Intraoperatively, we used the third-generation ICG-FS, the conventional ICG methods (CIM) emphasizing xenon-light (CIM-X), and the spectra-A method (SAM) emphasizing xenon-light (SAM-X), for IBL identification. Furthermore, 16 of the 106 patients (15%) could be simultaneously evaluated using old-generation ICG-FSs, CIM, and SAM. All images were completely quantified for illuminance and for three colors, red, green, and blue.

Results: IBLs were successfully identified in all the patients (100%) with no adverse events. The SAM-X significantly increased the illuminance, especially in the resecting segments, compared to the CIM (39.0 *versus* 22.2, $P < 0.01$) and SAM (39.0 *versus* 29.3, $P < 0.01$), with enhanced red color compared to the CIM (33.1 *versus* 21.9, $P < 0.01$) and SAM (33.1 *versus* 14.0, $P < 0.01$). Furthermore, the SAM-X significantly increased the illuminance contrast compared to the CIM-X (34.1 *versus* 15.3, $P < 0.01$).

Conclusions: The present study suggests that the SAM-X potentially provided images with the highest visibility and colorfulness compared to the older generation ICG-FSs or CIM-X. Secure IBL identification can be more easily and safely performed using the SAM-X.

Funding: No funding.

* *Corresponding author.* Aichi Cancer Center Hospital, Department of Thoracic Surgery, 〒464-8681, 1-1 Kanokoden, Chikusa-ku, Nagoya City, Aichi-ken, Japan. Tel.: (+81) 052-762-6111; fax: (+81) 052-764-2963.
E-mail address: h-kuroda@aichi-cc.jp (H. Kuroda).

0022-4804/$ – see front matter
https://doi.org/10.1016/j.jss.2020.11.028

Introduction

In recent years, sublobar resection has been gradually recognized as one of the standard treatment options for medically complicated patients with early-stage nonsmall cell lung cancer (NSCLC). Since the prevalence of small-sized NSCLC and elderly populations have been increased, sublobar resection has been widely performed in general practice.[1-4] More recently, the significance of systematic lymph node dissection procedures, as well as adequate oncological margin of thoracoscopic anatomical segmentectomy (TAS), have been investigated. Based on previous studies, our institutional criteria for performing a curative TAS for primary nonsmall cell lung cancer (NSCLC) are as follows: a small tumor size (≤20 mm in diameter) with a ratio of consolidation to a whole tumor (≤0.5) when the lung setting is used and a maximum size of 2 mm or less when the mediastinal setting is used on computed tomography (CT).[5-7] During a TAS, it is important to appropriately dissect the intersegmental plane based on an accurate intersegmental boundary line (IBL), in order to secure sufficient oncological margin and to preserve pulmonary function.[3,4] To date, we have detected IBLs in more than a total of 200 patients via the methods involving intravenous indocyanine green (ICG) using fluorescence imaging systems (ICG-FS) (Karl Storz; Tuttlingen, Germany) (Fig. 1A).

Since the commercial release of the first-generation ICG-FS, imaging the IBLs involves consecutively capturing images of the subject to consecutively generate image data. In our previous report that investigated the first-generation ICG-FS, "conventional ICG method" (CIM), we documented risk factors of unfavorable visibility of IBLs in 71 patients who had undergone TAS, and we noted for the first time that ICG fluorescence images were quantified for two concepts of "illuminance."[8] We concluded that the formation of IBLs was successfully visualized in 98.6% of the cases; however, unfavorable visibility may potentially occur in patients who are heavy smokers or in those who exhibit a low attenuation area (>1.0%) on computed tomography.

The development of the second-generation ICG-FS involves the use of the so-called "spectra-A method (SAM)" that facilitates improved visualization with the following three different image enhancement modes: (1) the Clara mode for a more homogeneous brightness level and more dynamic range, (2) the chroma mode with a higher contrast level, and (3) the spectra mode that is characterized by a shift in colors to support tissue differentiation. On using this system, we reported that the formation of IBLs was successfully visualized in all patients (100%). Also, we concluded that the SAM is a safe and promising noninvasive alternative like the CIM and that it was more effective rather than CIM by overcoming the disadvantages.[9]

Recently, the third-generation ICG-FS that includes an additional xenon light feature that can be implemented with the CIM and SAM was commercially released. We named the new methods "CIM emphasizing xenon-light" (CIM-X) and "SAM emphasizing xenon-light" (SAM-X), respectively. By comparing these systems to the older generation systems, we can investigate the specifics regarding the most important characteristics associated with fluorescent images emphasized by xenon light. The aim of this study was to examine the safety, feasibility, and effectiveness of the novel ICG-FSs, CIM-X and SAM-X, in the identification of IBLs in comparison to those of the older ICG-FSs.

Materials and methods

Study design and patients

This study was approved by the institutional review board of Aichi Cancer Center Hospital (approval No. 218-1-327). All the protocols were performed in accordance with the relevant

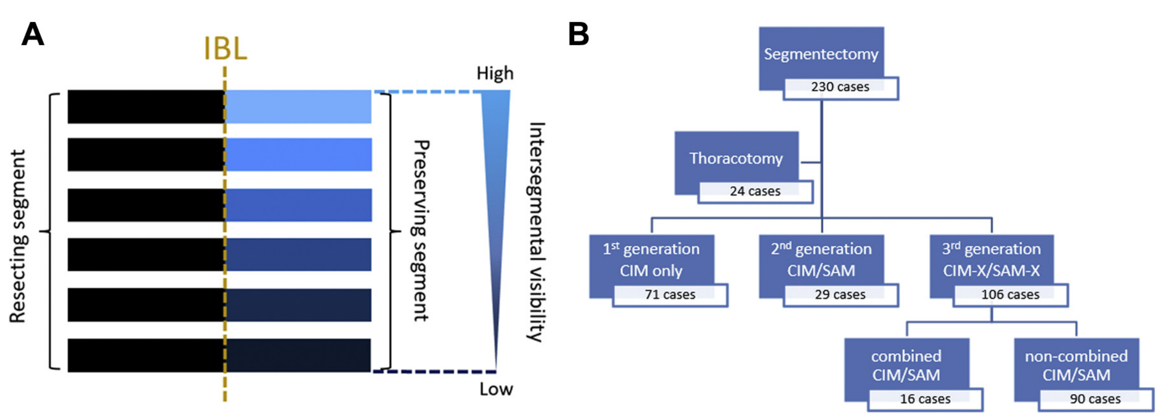


Fig. 1 – An illustration of the intersegmental visibility associated with the indocyanine green (ICG) fluorescence imaging system and algorism. (A) The right-sided bars show the preserving segments, and the left-sided bars, the resection ones. The intersegmental boundary line (IBL) is indicated by the golden dashed line in the center. The top bar shows the best visibility for IBLs, and the bottom, the worst visibility. (IBL: intersegmental boundary line) (B) Patient algorism for the patients who underwent various segmentectomies using each generation. CIM = conventional ICG method; SAM = spectra A method; CIM-X = CIM emphasizing xenon light; SAM-X = SAM emphasizing xenon light. (Color version of the figure is available online.)

local guidelines. Written informed consent was obtained from all the eligible patients before TAS was performed.

We prospectively studied 106 consecutive patients who underwent TAS performed using the CIM-X and SAM-X for IBL identification (Fig. 1B) at Aichi Cancer Center Hospital between October 2015 and October 2017. In addition, during the initial 3 mo of this study period, 16 of the 106 patients (15%) simultaneously underwent TAS using old-generation ICG-FS, CIM, and SAM (Fig. 2). Patients who were clinically suspected of having primary lung cancers (n = 94, 89%) based on the guidance of our institutional indication criteria or the metastatic lung tumor (n = 12, 11%) were considered as surgical candidates on the multidisciplinary tumor board. Among the patients with primary lung cancers (n = 78), 45 (58%) underwent curative TAS, and 33 (42%) underwent palliative TAS. Indications for curative TAS as follows: (1) an NSCLC patient who can tolerate lobectomy, (2) a small tumor size (≤20 mm diameter) with a ratio of consolidation (≤0.5) in the lung setting CT, and (3) a maximum size of 2 mm or less in the mediastinal setting CT. Otherwise, the cases that did not meet the criteria above were considered to be palliative. The exclusion criteria were previous pulmonary resection procedures in the same lobe and a history of allergic events to iodine or ICG. The technical details of the procedure and the timing of the intravenous ICG injection have been published previously.[8,9] Variables such as the age, sex, body mass index, Brinkman index, side, and tumor location were obtained from patient medical records.

Indocyanine green fluorescence imaging system

ICG fluorescence imaging is commonly used for intraoperative perfusion assessment in thoracic surgery, as well as in neuro, hepatobiliary, and colon surgeries. Bound to lipoproteins in the bloodstream and excited by near-infrared range energy (805 nm), ICG emits fluorescent light with a wavelength peaking at 835 nm. In our study, this effect is made visible with the commercially available IMAGE1 S camera platform and a D-Light P light source.

In the latest generation ICG-FS, the light source incorporates an optical filter that adds parts of the visible xenon light to the near-infrared excitation light. We used this particular feature for the CIM-X and SAM-X. In its standard configuration, the camera features a spectral color-shifting mode called spectra-A that is usually used to support tissue differentiation or for the observation of fine capillary vessels. The effect of the shifting colors also becomes apparent when spectra-A is used along with ICG visualization. In our research, this combination that includes the special excitation light source and camera system with color shifting technology was made use of in the SAM and SAM-X.

Methods used for image analyses

The patient demographic data and medical records were collected immediately following surgery. The intraoperative ICG fluorescent image captured during the peak emission was evaluated and analyzed using an image analysis software (Photoshop Elements 6.0, Adobe Systems Inc, San Jose, CA). All the images were quantified for illuminance and the three colors, red, green, and blue (RGB). The method used to quantify and analyze these images was as previously reported.[8,9]

Outlined below are the parameters associated with illuminance and color that we evaluated:

Illuminance
p1: The number of pixel peaks of resecting segment illuminance.

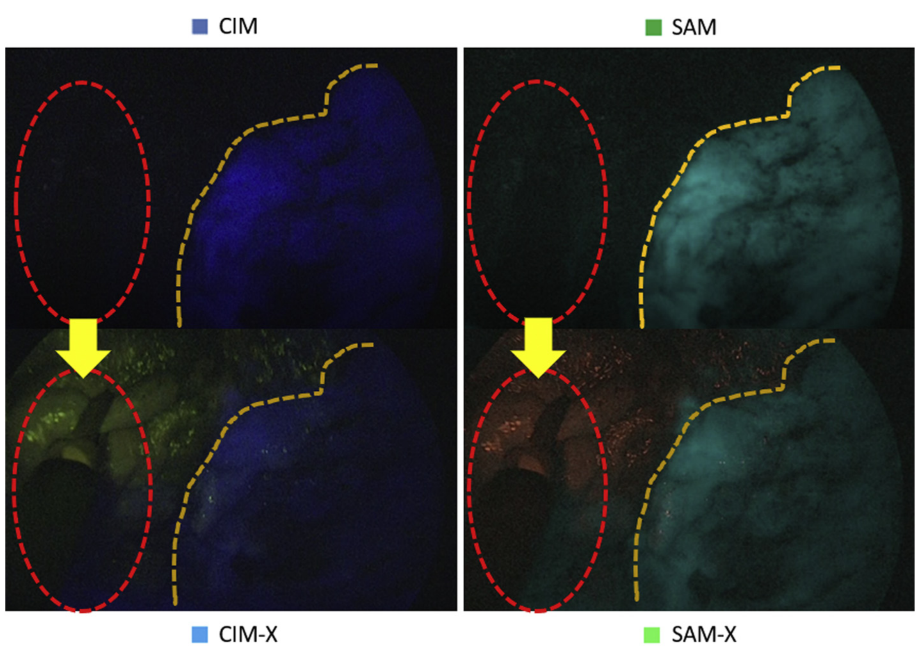


Fig. 2 – The representative simultaneous four indocyanine green (ICG) fluorescence images for intersegmental boundary line (IBL) identification in a case. The golden dashed line indicates the IBL and the red dashed circles show the thoracoscopic forceps in the resecting segments. CIM = conventional ICG method; SAM = spectra A method; CIM-X = CIM emphasizing xenon light; SAM-X = SAM emphasizing xenon light. (Color version of the figure is available online.)

p2: The number of pixel peaks of preserving segment illuminance.

Δp: The value obtained by subtracting the two peak values, p1 and p2, which is an indication of the intersegmental illuminance contrast.

Color

The average and total values associated with the RGB colors.

Statistical analysis

Student's *t*-test, the Mann–Whitney *U* test, and Fisher's exact test were used for the comparisons between combined CIM/SAM patients and CIM-X/SAM-X patients. The continuous variables that were normally distributed were summarized as mean and standard deviation, and the others were summarized as median and interquartile range. All statistical analyses were performed using JMP for Windows (version 13.0, SAS Institute, Cary, NC). All the *P* values were two-sided, and $P < 0.05$ was considered significant.

Results

Table 1 demonstrates the clinical background of the 106 patients who participated in this study. The median age was 68 years, 51 of them (48%) were male, and 53 (50%) did not have a smoking history. There were 29 (27%) heavy smokers with a pack-year of more than 40. Left upper lobe lesion was the most frequent (36 cases: 34%), and 72 cases (68%) were histologically diagnosed as primary lung cancer. The primary organs for metastatic lung tumors ($n = 28$, 26%) were the rectum ($n = 8$), head and neck ($n = 6$), uterus ($n = 4$), colon ($n = 3$), bone and soft tissue ($n = 3$), and others ($n = 4$). As a result, in all 106 cases, TAS was performed as planned preoperatively. IBL identification using the CIM-X and SAM-X was successful in all 106 patients (100%) with no adverse events related to the intravenous ICG administration. Furthermore, IBL identification was also successful in all the 16 cases in which we used both the CIM and SAM simultaneously (Fig. 2). No significant differences were found in the clinical background between the 16 cases and the 106 cases of the original cohort (Table 2).

First, regarding the illuminance, in the case of p1, the CIM-X demonstrates a significantly higher value than the CIM (36 *versus* 22, $P < 0.01$), and the SAM-X yielded a significantly higher value than the SAM (39 *versus* 29.3, $P < 0.01$) (Fig. 3A). On the other hand, there was no significant difference between the values obtained by using the CIM-X and SAM-X (36 *versus* 39, $P = 0.37$). In the case of p2, the SAM-X yielded a significantly higher value than the CIM (73 *versus* 32, $P < 0.01$) and CIM-X (73 *versus* 52, $P < 0.01$), but there was no significant difference when compared to the value obtained with using the SAM (73 *versus* 76, $P = 0.80$) (Fig. 3B). Based on Δp, the SAM yielded the highest value when compared to the values obtained among all these four methods; however, there was no significant difference from the value obtained by using the SAM-X (34 *versus* 46, $P = 0.16$). These results indicate that the spectra-mode had sufficient functions in contrast to the other modes irrespective of the xenon light feature. The xenon-light provides more brightness in the resected segment compared with the older generation systems. The SAM-X yielded high values for all the RGB colors and displayed colorful images. The SAM tended to generate images that were higher in contrast (Fig. 3C).

Table 1 – Patient characteristics.

Characteristics ($n = 106$)	Values
Age, y	68 (39–86)
Sex, male	51 (48)
Body mass index	21.8 (15.4–31.0)
Smoking, never	53 (50)
Pack-year	23.1 (0–180)
Clinical diagnosis	
Primary lung cancer	78 (74)
Metastatic lung tumor	28 (26)
Tumor location	
Right upper lobe	24 (23)
Right lower lobe	17 (16)
Left upper lobe	36 (34)
Left lower lobe	22 (21)
Other	7 (6)
Surgical time, min	180 (79–349)
Blood loss, mL	5 (0–790)
Intraoperative complication	
Pulmonary artery bleeding	1 (1)
Conversion	1 (1)
Intersegmental boundary line identification	
Yes	106 (100)
Allergic reaction for indocyanine green	
Yes	0 (0)
Pathological diagnosis	
Primary lung cancer	72 (68)
Metastatic lung tumor	28 (26)
Other	6 (6)
Postoperative recurrence	
Yes	0 (0)
Prognosis, dead	0 (0)

Values are no. of patients (%) or median (range).

Second, the color analyses were performed using the same measurement range that was used for the illuminance. Regarding the red color, the CIM-X yielded significantly higher values than the CIM (38 *versus* 22, $P < 0.01$), and the SAM-X yielded significantly higher values than the SAM (33 *versus* 14, $P < 0.01$) (Fig. 4A). On the other hand, there was no significant difference between the values obtained by using the CIM-X and SAM-X (38 *versus* 33, $P = 0.17$). Regarding the green color, the SAM and SAM-X yielded the same value (67 *versus* 67, $P = 0.98$). However, the value obtained by using the CIM-X was significantly higher than that obtained by using the CIM (44 *versus* 25, $P < 0.01$). As expected, the SAM-X yielded a significantly higher value than the CIM-X ($P < 0.01$) (Fig. 4B). Regarding the blue color, there were no significant differences among the values obtained by using the four ICG-FSs (Fig. 4C).

Table 2 – Comparison of patient characteristics between the combined CIM/SAM group and CIM-X/SAM-X group.

Characteristics	Combined CIM/SAM group (n = 16)	CIM-X/SAM-X group (n = 106)	P value*
Age, y	70 (52–84)	68 (39–86)	0.12
Sex, male	9 (56)	51 (48)	0.60
Body mass index	22.5 (19.3–29.1)	21.8 (15.4–31.0)	0.54
Smoking, never	5 (31)	53 (50)	0.19
Clinical diagnosis			0.87
Primary lung cancer	13 (81)	78 (74)	
Metastatic lung tumor	3 (19)	28 (26)	
Tumor location			0.26
Right upper lobe	5 (31)	24 (23)	
Right lower lobe	3 (19)	17 (16)	
Left upper lobe	7 (44)	36 (34)	
Left lower lobe	0 (0)	22 (21)	
Other	1 (6)	7 (6)	
Surgical time, min	176 (133–210)	180 (79–349)	0.85
Blood loss, mL	5 (0–790)	5 (0–135)	0.97
Pathological diagnosis			0.90
Primary lung cancer	12 (75)	72 (68)	
Metastatic lung tumor	3 (19)	28 (26)	
Other	1 (6)	6 (6)	

Values are no. of patients (%) or median (range).
CIM = conventional indocyanine green method; CIM-X = CIM emphasizing xenon-light; SAM = spectra-A method; SAM-X = SAM emphasizing xenon-light.
*P values are for the comparison between combined CIM/SAM group and CIM-X/SAM-X group.

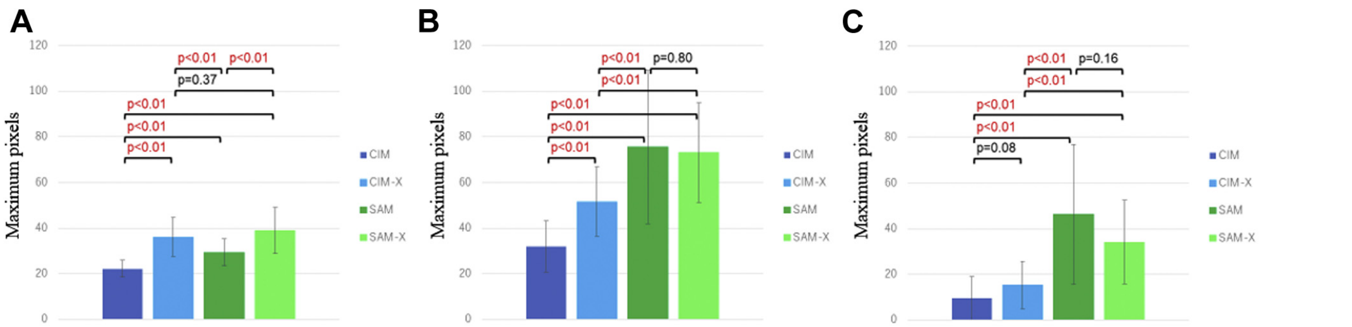
These results from our RGB analyses confirmed the details outlined in commercial documents regarding the technical shift in colors resulting from a combination of filtering the wavelengths of dominant red colors and the peculiar expansion of the remaining color information that is rearranged to the full range of the visible spectrum.[10] The sum of the values associated with the three colors were significantly lower with the CIM than with the other three ICG-FSs (Fig. 4D). These results indicated that the SAM-X yielded high values for all the RGB colors and displayed colorful images.

Comment

We have previously reported that ICG-FS was safe, feasible, and efficacious for identifying IBLs during TAS.[8,9] First, by analyzing 83 cases with the first-generation system the CIM, we confirmed a high success rate (99%) in the identification of IBLs; however, the intersegmental visibility was decreased in patients with smoking habit and lung emphysema.[8] Second, by analyzing 29 cases that were examined using the second-generation system the SAM with using simultaneous intraoperative comparisons, we successfully identified IBLs in all the cases, and we postulated the improvement in the visibility of IBLs.[9] In this study, a third-generation system that is characterized by a subsidiary xenon-light feature demonstrated successful identification of IBLs using the CIM-X and SAM-X in all the cases (100%). Similarly, IBL identification was achieved in 16 cases in which the old system without xenon light enhancement was also evaluated at the same time. In terms of illuminance, SAM was used since the development of the second-generation system is promising in facilitating the stabilized visibility of IBLs regardless of whether xenon-light is used. However, the xenon-light feature resulted in better visibility in the resected segment compared to the older generation systems. In terms of color, the SAM-X images were composed of the highest number of pixels in all the RGB colors.

Regarding the identification (?) of IBLs during TAS, several effective options, including creating an inflation-deflation line, have been proposed to identity IBLs.[11,12] However, in recent years, reports on the use of ICG-FSs during TAS for the identification of IBLs are increasing.[8,9,13-16] Misaki *et al.* conducted a clinical trial that investigated segmentectomy using an ICG-FS, and they succeeded in visualizing the differential blood flow of the pulmonary artery in the lungs.[13,14] In addition, Tarumi *et al.* performed TAS using an ICG-FS and reported that they successfully identified IBLs in 11/13 (85%) patients after the dissection of the hilar structures.[15]

Integrity was verified by the second-generation SAM. In other words, the ICG-FS was already completely developed before the commercial release of the third-generation systems, the CIM-X and SAM-X.[9] In fact, in this study, we investigated the clinical usefulness of the third-generation CIM-X and SAM-X in both illuminance and color in comparison with those of the second-generation SAM or CIM. Therefore, we postulated that the third-generation ICG-FS yielded significantly better p1 values than the second-generation system, which is believed to be a change brought about by the emphasizing xenon-light.



CIM	22.2 ± 3.7
CIM-X	36.0 ± 8.5
SAM	29.3 ± 5.9
SAM-X	39.0 ± 10.1

CIM	31.9 ± 11.2
CIM-X	51.6 ± 15.1
SAM	75.5 ± 33.7
SAM-X	73.1 ± 21.8

CIM	9.6 ± 9.5
CIM-X	15.3 ± 10.3
SAM	46.2 ± 30.6
SAM-X	34.1 ± 18.4

Fig. 3 – Comparison of the average number of maximum pixels for illuminance using the four indocyanine green (ICG) fluorescence images. (A) p1: The comparison in the resecting segment, (B) p2: The comparison in the preserving segment, and (C) Δp: The comparison of illuminance contrast. CIM = conventional ICG method; SAM = Spectra A method; CIM-X = CIM emphasizing xenon light; SAM-X = SAM emphasizing xenon light. (Color version of the figure is available online.)

It is necessary to mark the lung surface immediately along the IBL because ICG is rapidly washed out by blood flow of lung parenchyma. Mun *et al.* reported that the average time necessary to identify IBLs with intravenous ICG injection was 70 s,[16] for which they used a method similar to our method. While making these marks under thoracoscopy, we commonly use electrocautery; however, the lower level of illuminance and longer IBL result in a further delay in this step because of the dark background, especially in the case of resected segments. Indeed, we sometimes encountered difficulties in recognizing an electrocautery site on the resected segments to create a line along the IBL. Mun *et al.* also pointed out the IBL marking required to be cautious to prevent accidental injuries of the pulmonary artery and vein with electrocautery, as the background generated with the ICG-FS is usually dark.[16] We considered that the obvious change that could potentially solve the problems associated with the marking of lung surface might be the usage of an ICG-FS with an additional xenon-light feature (Fig. 2).

The second-generation system, SAM, resulted in a significant increase in both p1 and p2 compared to the first generation, although the increase was smaller in p1 than in p2. With the SAM, although we successfully identify IBLs in all the cases, different from the fluorescent areas, the entire background of the lung parenchyma appeared dark. For resolving this problem, the manual switch is operated in the marking of the lung surface. In this system, the electrocautery is controlled by an on/off feature that is used to turn on and turn off the guiding light, which is turned off in the SAM. Ideally, there should be an increase in the p1 value while the Δp value is maintained; however, we encountered a concern involving a decrease in the Δp value corresponding to an increase in the p1 value, which resulted in a deterioration of the visibility. The third-generation ICG-FS resulted in the resolution of this concern via the change that emphasizes xenon-light, especially in the spectrum, from green to yellow. This study postulated that the SAM-X successfully and significantly increased the p1 value compared to the SAM while maintaining the Δp value comparable with the SAM. The remarkable improvement of the visibility of the surgical instruments in the resecting segment and the clear identification of circumstance structures on the monitor are evident when compared with the results obtained with former system; this allows for the surgeons to more safely and easily operate along with the formation of IBLs.

Both CIM-X and SAM-X obtained by the third-generation ICG-FS showed a significant improvement in red color compared to the CIM and SAM obtained by the second generation. The third-generation ICG-FS emphasized the xenon light, and it is considered that this change improved the red color value on the image of SAM-X and CIM-X. Therefore, we consider red to be the most important color that contributed to improved image visibility in the third-generation ICG-FS. However, regarding the sum value of the RGB color, the SAM, CIM-X, and SAM-X all yielded significantly better results than the CIM, but there were no significant differences among the three groups. Based on these results, it was difficult to ascertain whether the RGB colors independently contributed to the favorable visibility while comparing the results between the second and third-generation ICG-FSs.

The limitations of this study were that it was performed in a single institution, and it included a small sample size. In particular, because of restriction on the applicable period corresponding to the older generation system, the fact that the old-generation and new-generation systems could simultaneously be used in only 16 cases might have affected the results of this study. However, in these 16 cases, there were no significant differences in patient backgrounds compared to the entire sample. In the future, further prospective, large-scale, multi-institutional studies are warranted to confirm our results.

In conclusion, the third-generation ICG-FS, especially the SAM-X, has proved its usefulness in IBL identification as compared to the older generation systems, which is in addition to making the IBL marking process safer and easier. The

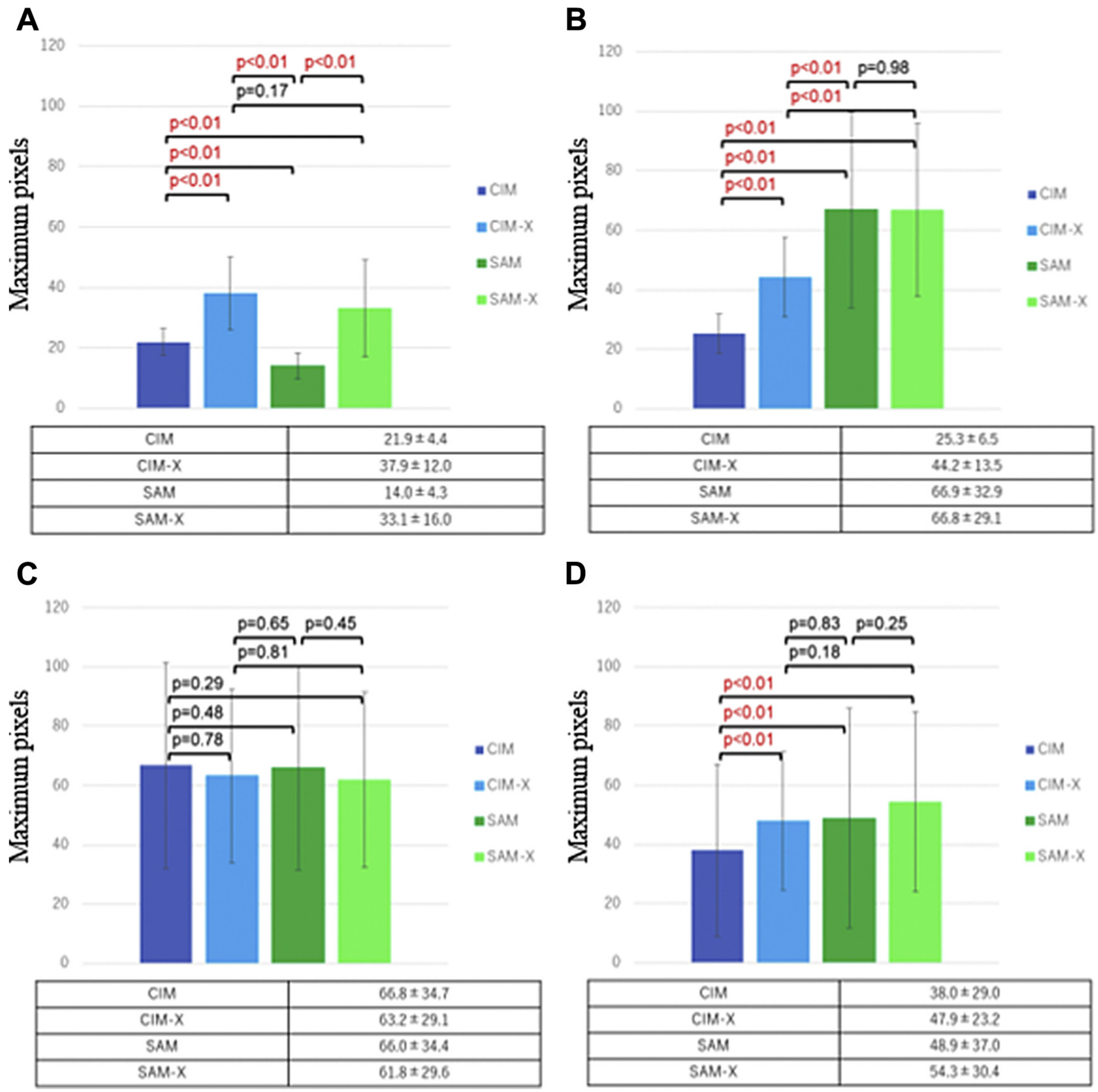


Fig. 4 – Comparison of the average number of maximum pixels for the red, green, and blue (RGB) colors using the four indocyanine green (ICG) fluorescence images. (A) The comparison of the red color values. (B) The comparison of the green color values; (C) The comparison of the blue color values; and (D) The comparison of the sum of RGB color values. CIM = conventional ICG method; SAM = spectra A method; CIM-X = CIM emphasizing xenon light; SAM-X = SAM emphasizing xenon light. (Color version of the figure is available online.)

SAM-X can be considered to be the most useful and safe ICS-FS that can be used during TAS.

Acknowledgment

Authors' contributions: All authors conduced to the work reported in this manuscript. T.M. and H.K. played a major part in conceiving and designing the study, collecting the imaging data, interpreting the data, and writing this manuscript. Y.T. assisted with data analysis and interpretation. Y.O, T.N., and N.S participated in clinical data collection and article revisions. H.M. helped conceiving and designing the study, and finally approved the final version of this manuscript. All authors finally approved this manuscript before submission.

The abstract of this article was presented at the IASLC's 19th World Conference on Lung Cancer in Toronto, Canada as a poster presentation.

Disclosure

All the authors have no conflicts of interest, such as any personal or financial support or author involvement with organizations with a financial interest to disclose.

REFERENCES

1. Yano M, Yoshida J, Koike T, et al. Japanese Association for Chest Surgery. Survival of 1737 lobectomy-tolerable patients who underwent limited resection for cStage IA non-small-cell lung cancer. *Eur J Cardiothorac Surg*. 2015;47:135–142.
2. Lung Cancer Study Group, Ginsberg RH, Rubinstein LV. Randomized trial of lobectomy versus limited resection for T1N0 non-small cell lung cancer. *Ann Thorac Surg*. 1995;60:615–623.
3. Wolf AS, Richards WG, Jaklitsch MT, et al. Lobectomy versus sublobar resection for small (2cm or less) non-small cell lung cancers. *Ann Thorac Surg*. 2011;92:1819–1823.
4. Nomori H, Mori T, Ikeda K, et al. Segmentectomy for selected cT1N0M0 non-small cell lung cancer: a prospective study at a single institute. *J Thorac Cardiovasc Surg*. 2012;144:87–93.
5. Sakao Y, Kuroda H, Mun M, et al. Prognostic significance of tumor size of small lung adenocarcinomas evaluated with mediastinal window settings on computed tomography. *PLoS One*. 2014;9:e110305.
6. Sakakura N, Inaba Y, Yatabe Y, et al. Estimation of the pathological invasive size of pulmonary adenocarcinoma using high-resolution computed tomography of the chest: a consideration based on lung and mediastinal window settings. *Lung Cancer*. 2016;95:51–56.
7. Kuroda H, Mori S, Tanaka H, et al. Prognostic significance of combined radiologic imaging modalities for prognosis of clinical IA adenocarcinomas. *Oncotarget*. 2017;9:10745–10753.
8. Iizuka S, Kuroda H, Yoshimura K, et al. Predictors of indocyanine green visualization during fluorescence imaging for segmental plane formation in thoracoscopic anatomical segmentectomy. *J Thorac Dis*. 2016;8:985–991.
9. Kuroda H, Yoshida T, Arimura T, et al. Novel development of Spectra-A using indocyanine green for segmental boundary visibility in thoracoscopic segmentectomy. *J Surg Res*. 2018;227:228–233.
10. Turner PL, Mainster MA. Circadian photoreception: ageing and the eye's important role in systemic health. *Br J Ophthalmol*. 2008;92:1439–1444.
11. Atkins BZ, Harpole Jr DH, Mangum JH, et al. Pulmonary segmentectomy by thoracotomy or thoracoscopy: reduced hospital length of stay with a minimally-invasive approach. *Ann Thorac Surg*. 2007;84:1107–1112. discussion 1112-3.
12. Okada M, Mimura T, Ikegaki J, et al. A novel video-assisted anatomic segmentectomy technique: selective segmental inflation via bronchofiberoptic jet followed by cautery cutting. *J Thorac Cardiovasc Surg*. 2007;133:753–758.
13. Misaki N, Chang SS, Gotoh M, et al. A novel method for determining adjacent lung segments with infrared thoracoscopy. *J Thorac Cardiovasc Surg*. 2009;138:613–618.
14. Misaki N, Chang SS, Igai H, et al. New clinically applicable method for visualizing adjacent lung segments using an infrared thoracoscopy system. *J Thorac Cardiovasc Surg*. 2010;140:752–756.
15. Tarumi S, Misaki N, Kasai Y, et al. Clinical trial of video-assisted thoracoscopic segmentectomy using infrared thoracoscopy with indocyanine green. *Eur J Cardiothorac Surg*. 2014;46:112–115.
16. Mun M, Okumura S, Nakao M, et al. Indocyanine green fluorescence-navigated thoracoscopic anatomical segmentectomy. *J Vis Surg*. 2017;3:80.