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New Quantitative Analysis Method Using HyperEye Medical System Image for Coronary Artery Bypass Grafting

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Abstract

Purpose: The current evaluation by indocyanine green angiography in coronary artery bypass patients has been performed by qualitative analysis. We devised an original quantitative analysis method using Image J.

Methods: Indocyanine green angiography movie was converted to spatiotemporal images. Using the spatiotemporal image, an indocyanine green fluorescence intensity curve was drawn and converted to a first-derivative (acceleration) curve. Indocyanine green angiography evaluations were classified into four types. We collected the peak indocyanine green fluorescence intensity value (peak-I) and both time interval and ratio of maximum indocyanine green acceleration value (max dI/dt) between the mid and distal portions of the graft.

Results: In 61 left internal thoracic artery grafts, 49 were patent and 12 were abnormal on CAG. There were significant differences between peak-I at the mid portion of the graft (221.47 ± 39.33 vs. 184.82 ± 40.15 gray scale) and time delay with max dI/dt (0.45 ± 1.28 vs. −1.00 ± 1.25 s), but there was no significant difference in the ratio of max dI/dt between patent and abnormal grafts.

Conclusions: The spatiotemporal image method may become a model of the analysis software and the time interval of max dI/dt may become a predictor for future graft failure.

Keywords: Coronary artery bypass; Decision support techniques; Indocyanine green angiography

Introduction

Indocyanine green angiography (ICG-AG) is used to assess grafts for coronary artery bypass grafting (CABG) [1-4]. Previously, we developed a prototype color ICG-AG system, the HyperEye Medical System (HEMS; Mizuho IKAKOGYO Inc., Tokyo, Japan), and have used it with TTFM (VeriQ; Medistim, Oslo, Norway) for intraoperative graft evaluation since 2007 [5,6]. Yamamoto et al. reported the technique of quantitative assessment by using HEMS [7]. However, until now, there is no available analysis software program for quantitative evaluation using HEMS Image.

Recently, SPYTM and SPY–Q image analysis tools (Novadaq Technologies, Inc., Ontario, Canada) have been commonly used in breast reconstruction, flap reconstruction, and gastroenterology surgeries [8-14]. This system visualizes tissue vascularity and perfusion with color gradation and quantitatively analyzes flow volumes in the perfusion area. In cardiac surgery, Ferguson et al. reported a new method of CABG using SPYTM and SPY–Q during fractional flow reserve guidance [15]. They demonstrated that SPY–Q had no change in regional myocardial perfusion, suggesting anatomic, but nonfunctional stenoses of the target epicardial coronary arteries. For *in-situ* arterial grafts, imaged competitive flow was associated with nonfunctional stenoses of the target epicardial coronary artery.

Moreover, ROIs version U11437 software program (Hamamatsu Photonics K.K., Hamamatsu, Japan) was used for peripheral artery disease [16]. Igari et al. measured the time elapsed from the fluorescence onset to half the maximum intensity (T1/2). The value of T1/2 showed comparable outcomes of revascularization procedures.

SPY–Q and ROIs version U11437 are good systems for quantitative analysis of vascular flow and perfusion, but the drawback of this analysis software is the limited use of each device. To perform quantitative analysis of HEMS data, we needed to develop an original analysis software program. Therefore, with the use of the free image processing software program Image J we devised an original analysis method for evaluation of intragraft flow and classified the characteristics of flow dynamics, which was captured by HEMS.

Although we devised a measurement method for changes in ICG fluorescence intensity in the present study, the parameters for better quantitative evaluation are unknown. We agreed that the rich native coronary artery flow decreased the intragraft flows during CABG. We hypothesized that both the acceleration values for the change in ICG intensity and the time interval between the mid and distal portions of the graft would show derangements in the abnormal grafts on postoperative CAG.

The purpose of present study was to determine the effectiveness of the original analysis method and to investigate the relationship between the HEMS original parameters and CAG outcome during CABG.

Materials and Methods

Patients and data collection

In this retrospective study, we were able to collect sixty-eight ITA graft images which underwent isolated CABG with complete TTFM, HEMS, and postoperative angiographic assessments. Only 12 among sixty-eight grafts were abnormal on postoperative CAG. *In-situ* LITA to LAD grafts were examined in this study because there was a difference between the flow dynamics of ITA graft and that of AC bypass graft.

Variable	Patients (n=68)	(%)
Age (years)	70.4 ± 9.1	
Gender		
Male	55	81%
Female	13	19%
Diabetes mellitus	21	31%
Oral medication	11	16%
On insulin	10	15%
Cerebrovascular disease	9	13%
Preoperative dialysis	2	3%
Peripheral arterial disease	4	6%
Previous PCI	12	18%
History of MI	16	24%
Operative data		
Total graft	196	
In situ arterial	82	42%
AC bypass	114	58%
OPCAB	67	99%
On-pump beating heart	1	1%
ONCAB (arrested heart)	0	0%
Status		
Elective	63	93%
Urgent	5	7%
Emergent	0	0%

Values are presented as numbers or mean ± standard deviation
PCI: percutaneous coronary intervention; MI: myocardial infarction; AC bypass: aortocoronary bypass graft; OPCAB: off-pump coronary artery bypass graft; CABG: coronary artery bypass graft; ONCAB (arrested heart): on-pump coronary artery bypass graft with arrested heart.

Table 1: Patient characteristics.

Table 1 shows the patient demographics. The standard procedure at our institution has been off-pump coronary artery bypass with *in-situ* left internal thoracic artery (LITA) graft to the left anterior descending (LAD) artery and a saphenous vein graft to the circumflex and/or right coronary artery lesion [aortocoronary artery bypass (AC bypass)].

The criteria for graft revision were both mean flow (MF) of <5 ml/min, pulsatility index (PI) of >5, or diastolic filling ratio (DF) of <50% with TTFM and no flow fluorescence with the HEMS. However, HEMS evaluation was depended on visual assessment only (Figure 1). For CAG after surgery, the following classifications were used: (1) patent graft, defined as no occlusion or graft stenosis of <75% and native coronary artery perfusion that was dependent on the ITA graft; and (2) abnormal graft, defined as native coronary artery perfusion that was marginally dependent on ITA graft flow and/or presence of graft occlusion, graft string, or severe graft stenosis (>75%).

Measurement method for ICG fluorescence intensity, classification of flow dynamics, and parameter for quantitative analysis

We retrospectively collected digital data at both mid and distal (near anastomosis) portions of the ITA graft using HEMS image (Figure 2).

For measurement of ICG fluorescence intensity value, HEMS movie was stabilized and converted to spatiotemporal image of the grafts. First, we cropped a region of interest (ROI) on the HEMS movie using video processing software (COREL Ulead Video Studio 12.0; Corel Japan Ltd., Tokyo, Japan). The cropped movie was stabilized by free video processing software (YouTube). Next, we imported the stabilized movie to a free image processing software (Image J) and converted it to spatiotemporal images automatically by selecting "Image," "Stacks," and "Reslice" menus. In addition, the "Output Spacing (pixels)" menu was set at ten pixels.Thereafter, we manually traced the intragraft line to plot the change in ICG fluorescence intensity. The data on change in ICG fluorescence intensity were saved as Excel data sheet, and the digital processing software (Igor Pro 3.0: HULINKS Inc., Tokyo, Japan) draw ICG fluorescence intensity curve by using Excel data (Figure 3).

On the first inspection of the ICG fluorescence curve, the wave profile was classified into the following four major groups in this study (Figure 3):

1. Graft-dependent perfusion type (patent type), which was defined as increase in ICG fluorescence intensity along the time series.

2. Native coronary artery preceding perfusion type (native precede type), which was defined as a change in ICG fluorescence intensity at the distal portion preceding that of the mid portion of the graft. In this group, when HEMS captured to and fro flow fluorescence at the distal portion of the graft, there was decrease in the peak ICG fluorescence intensity at the mid portion of the graft, compared with the distal portion.

3. Decrease of the ICG fluorescence intensity (decrease type), which was defined as a lower peak value of ICG fluorescence intensity at the distal portion compared with that of the mid portion of the graft (>200 grayscale at the mid portion and <150 grayscale at the distal portion).

4. Other type.

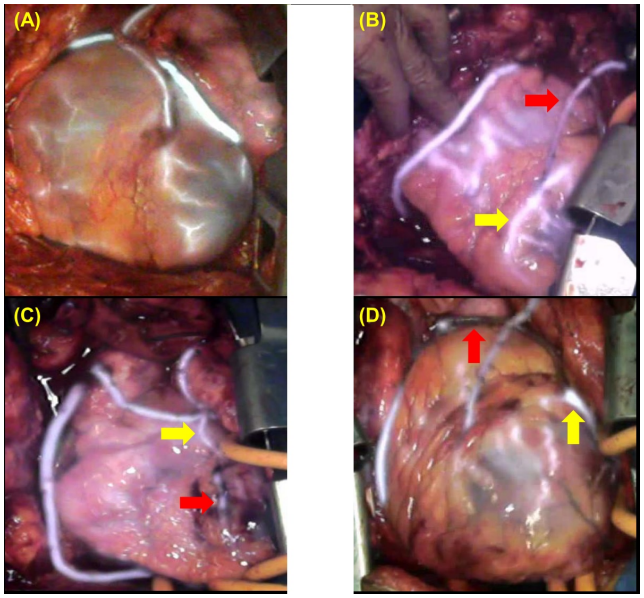

Figure 1: Current HEMS visual assessment. (a) Patent Flow Image. LITA to LAD and SVG to Diagonal graft were clearly visualized by HEMS. (b) Native coronary artery precede Image. LITA to LAD and SVG to RCA graft were captured by HEMS. ICG fluorescence intensity of the LAD (yellow arrow) was higher than that of the LITA graft (red arrow). (c) Decrease of ICG fluorescence intensity Image in Graft. LITA to LAD, SVG to Cx and SVG to RCA graft were captured by HEMS. ICG fluorescence intensity of the mid portion of the LITA graft (yellow arrow) was higher than that of the distal portion of the LITA graft (red arrow). (d) Occlusion Image. LITA to LAD, SVG to Diagonal and Cx (sequential) and SVG to RCA graft were captured by HEMS. ICG fluorescence intensity of the proximal portion of the SVG (yellow arrow) has no ICG fluorescence intensity (red arrow), but HEMS visualized SVG between diagonal and Cx (C-C bypass) (yellow arrow). LITA, left internal thoracic artery; SVG, Saphenous vein graft; LAD, left anterior descending artery; Cx, Circumflex artery; RCA, Right coronary artery; C-C bypass, coronary to coronary bypass; HEMS, HyperEye Medical System; ICG, indocyanine green.

In order to create new parameters for quantitative analysis by HEMS, we used a curve-fitting method (parametric analysis) to collect digital data. First, an n-polynomial approximation curve, such as

$$\text{Intensity (t)} = a^{n-1} \times t^{n-1} + a^{n-2} \times t^{n-2} + \ldots + a^{1} \times t + a \text{ (grayscale)}$$

was drawn by curve-fitting method and digital processing software (Igor Pro 3.0). Second, the first-derivative curve was drawn as,

$$\text{Intensity (t)} = a^{n-1} \times t^{n-2} + a^{n-2} \times t^{n-3} + \ldots + a^{1} \text{ (grayscale/s)}$$

to evaluate the acceleration value of the change in intensity.

We investigated polynomials of any degree to reconstruct the wave profile from the digital data and selected a 6-polynomial because it showed a greater tendency to match the changes in the waveform. In this study, we converted the 6-polynomial approximation curve to a first-derivative curve (acceleration curve) (Figure 3).

Using a 6-polynomial approximation curve and the first derivative curve, we collected the following parameters: (1) peak-I (grayscale): value of the peak ICG fluorescence intensity that was measured from the 6-polynomial approximation curve; (2) max dI/dt (grayscale/s): maximum acceleration value that was measured from the first-derivative curve; (3) Ratio-I: ratio of the peak ICG fluorescence intensity value (distal/mid portion); (4) Ratio-max dI/dt: ratio of the maximum acceleration value (distal/mid portion); (5) time delay with I (s): time interval to reach the peak ICG fluorescence intensity value between the mid and distal portions of the graft; and (6) time delay with max dI/dt (s): time interval to reach the maximum acceleration value between the mid and distal portions of the graft (Figure 4).

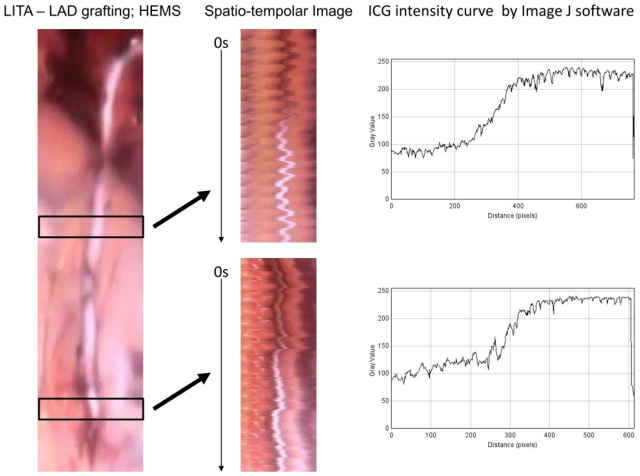

Figure 2: Spatiotempolar image and ICG fluorescence intensity curve. HEMS movie is cropped and stabilized by using YouTube movie editor (left figure). The Square areas on stabilization movie are converted to spatiotempolar images by the image processing software program, Image J (middle figure). Therefore, we manually trace the intragraft line to plot the change in ICG fluorescence intensity by using Image J (right figure). LITA, left internal thoracic artery; LAD, left anterior descending artery; HEMS, HyperEye Medical System; ICG, indocyanine green.

Statistical analysis

All continuous values were presented as mean ± standard deviation. Mann–Whitney U test was used to compare results between different group pairs. For all analyses, *P* value of <0.05 was considered to indicate statistical significance. The cut off value was calculated by ROC analysis. All analyses were performed by EZR (Saitama Medical Centre, Jichi Medical University), which is a graphical user interface for R (The R Foundation for Statistical Computing).

Results

Overall data analysis

Among 68 patients with available data for retrospective collection, 7 were excluded because of poor quality HEMS images. Therefore, this study included 61 patients who had 61 *in situ* LITA to LAD grafts for analyses. Postoperative CAG of the 61 grafts revealed that 49 grafts were patent and 12 were abnormal. Among the 12 abnormal grafts, 6

were occlusion or string grafts, 3 were severe graft stenosis, and 3 had poor perfusion.

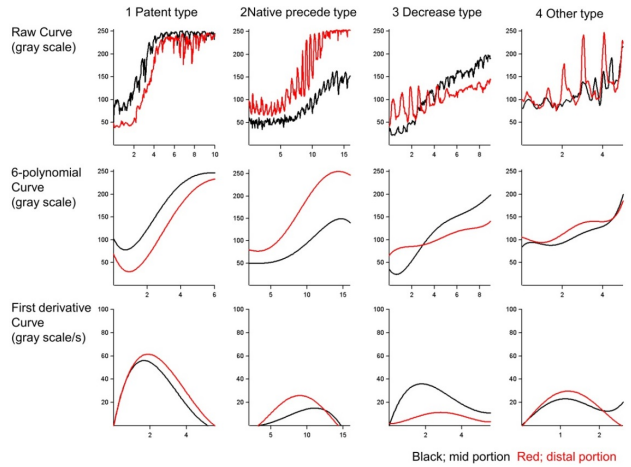

Figure 3: HEMS classification. The ICG fluorescence intensity curve is classified into major four groups: graft-dependent perfusion, native coronary artery preceding perfusion, decrease of the fluorescence intensity, and other type. Igor pro software program converts a raw ICG fluorescence intensity curve to the 6-polynomial approximation curve by using curve-fitting method. In a raw curve and the 6-polinomial approximation curve, X axis is the second and Y axis is the gray value. In addition, Igor pro software program converts a 6-polinomial approximation curve to the first derivative curve. The first derivative curve shows an acceleration value of the increasing of the ICG fluorescence intensity in each point. In the first derivative curve, X axis is the second and Y axis is the gray value/s in each HEMS type. The black line is the mid portion of the graft and the red line is the distal portion of the graft. HEMS, HyperEye Medical System; ICG, indocyanine green.

For the TTFM parameters assessed by postoperative CAG, there were significant differences in the MF (21.44 ± 13.35 vs. 13.75 ± 6.94 ml/min, $p<0.05$) and the PI (2.77 ± 1.38 vs. 3.8 ± 1.48, $p<0.05$) between patent and abnormal grafts.

According to our HEMS classification, 35 of 49 patent grafts on CAG were classified as patent type and 14 of 49 patent grafts on CAG were native precede type. In 4 of 14 native precede type patent grafts, the to and fro flow images were captured at the distal portion of the graft. On the other hand, among the 12 abnormal grafts on CAG, 8 were classified as native precede type, 3 were decrease type, and 1 was other type. In 6 of 8 native precede type abnormal grafts, to and fro flow was visualized at the distal portion of the graft.

There were significant differences among the six HEMS parameters, including the time delay with I (0.40 ± 0.91 vs. −0.83 ± 1.21 s, $p<0.01$); and the time delay with max dI/dt (0.45 ± 1.28 vs. −1.00 ± 1.25 s, $p<0.01$) (Table 2). In ROC analysis, the cut-off value for time delay with I was −0.207 (sensitivity 0.667, specificity 0.809, AUC 0.814) and the cut-off value for the time delay with max dI/dt was −0.454 (sensitivity 0.750, specificity 0.872, AUC 0.830).

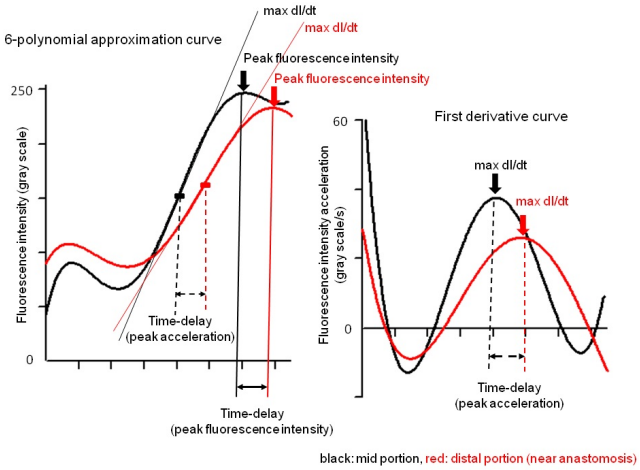

Figure 4: HEMS parameters. HEMS parameters are collected from a 6-polynomial approximation curve and the first derivative curve. A 6-polynomial approximation curve is created by using curve-fitting method (parametric analysis) here the first derivative curve directly shows an acceleration value in each point. We obtain the value of peak ICG fluorescence intensity and time-interval from 6-polynomial approximation curve. The value of peak acceleration and time-interval is measured from first derivative curve. HEMS, HyperEye Medical System; ICG, indocyanine green; Max dI/dt, maximum acceleration value

		CAG outcome		
		Patent graft (n=49)	**Abnormal graft (n =12)**	**P value**
Native stenosis	100%	10	0	
	99%	8	0	
	90%	13	4	
	75%	16	7	
	LMT 50%	0	1	
TTFM	MF (ml/min)	21.44 ± 13.35	13.75 ± 6.94	<0.05
	PI	2.77 ± 1.38	3.8 ± 1.48	<0.05
	DF (%)	73.67 ± 8.19	66.25 ± 15.43	N.S
HEMS	Patent type	35	0	
	Native precede type	14	8	
	Without to and fro flow	10	2	
	With to and fro flow	4	6	
	Decrease type	0	3	
	Other type	0	1	

HEMS parameter				
ICG intensity peak value	mid portion (gray scale)	221.47 ± 39.33	184.82 ± 40.15	<0.01
	distal portion (gray scale)	226.06 ± 34.63	204.03 ± 51.19	N.S
	ratio (distal/mid)	1.04 ± 0.16	1.15 ± 0.35	N.S
	time delay (s)	0.4 ± 0.91	−0.83 ± 1.21	<0.01
ICG intensity max acceleratio n value	mid portion (gray scale/s)	38.58 ± 16.21	32.04 ± 9.67	N.S
	distal portion (gray scale/s)	36.55 ± 15.92	32.59 ± 13.87	N.S
	ratio (distal/mid)	0.98 ± 0.28	1.07 ± 0.45	N.S
	time delay (s)	0.45 ± 1.28	−1.00 ± 1.25	<0.01

Values are presented as mean ± standard deviation. P value was evaluated by Mann–Whitney U test.

Native stenosis: native coronary artery stenosis; TTFM: transit time flowmetry; MF: mean flow; PI: pulsatility index; DF: diastolic filling; HEMS: HyperEye Medical System; ICG: indocyanine green; CAG: coronary angiography.

Table 2: Relationship between CAG outcome and HEMS evaluation for overall data.

Abnormal ITA graft by postoperative CAG/ native precede type by HEMS

Eight ITA grafts were abnormal by postoperative CAG and of the native precede type by HEMS. In these 8 grafts, the abnormalities detected by postoperative CAG were occlusion in 1, string graft in 4, stenosis of the anastomosis in 1, and low perfusion in 2.

Comparing the patent and abnormal grafts, there was a significant difference in the percentage with native coronary artery stenosis (88.3% ± 10.6% vs. 75.6% ± 12.4%, p<0.05), but there were no significant differences in TTFM parameters. Among the HEMS parameters, there were significant differences in time delay with max dI/dt (0.45 ± 1.28 vs. −1.61 ± 0.98 s) and the Ratio-max dI/dt (0.98 ± 0.28 vs. 1.26 ± 0.33) (p<0.05 for all) (Table 3). In ROC analysis, the cut-off value for each parameter was −0.484 s (sensitivity 1.000, specificity 0.872, AUC 0.960) for time delay with max dI/dt and 1.005 (sensitivity 0.875, specificity 0.617, AUC 0.747) for the Ratio-max dI/dt.

Abnormal ITA graft by postoperative CAG/ decrease type by HEMS

Three ITA grafts were abnormal by postoperative CAG and of the decrease type by HEMS. In these 3 grafts, the abnormalities detected by postoperative CAG were stenosis of the anastomosis in 1, stenosis of the distal portion of the graft in 1, and low perfusion in 1.

	CAG outcome					
	Patent graft (n=49)	Abnormal graft (n=12)				
		HEMS classification				
		Native precede type (n=8)	P value	Decrease type (n=3)	P value	Other type (n=1)
ICG intensity peak value						
mid portion (gray scale)	221.47 ± 39.33	182.07 ± 44.07	<0.05	207.44 ± 14.98	N.S	139.06
distal portion (gray scale)	226.06 ± 34.63	234.63 ± 29.74	N.S	144.31 ± 8.01	<0.01	138.37
ratio (distal/mid)	1.04 ± 0.16	1.33 ± 0.25	<0.01	0.7 ± 0.01	<0.01	1
time delay (s)	0.4 ± 0.91	−1.21 ± 1.33	<0.01	−0.10 ± 0.36	N.S	0
ICG intensity max acceleration value						
mid portion (gray scale/s)	38.58 ± 16.21	30.95 ± 9.35	N.S	37.9 ± 10.63	N.S	23.15
distal portion (gray scale/s)	36.55 ± 15.92	37.87 ± 12.26	N.S	19.42 ± 12.51	N.S	29.8
ratio (distal/mid)	0.98 ± 0.28	1.26 ± 0.33	<0.05	0.49 ± 0.19	<0.01	1.29
time delay (s)	0.45 ± 1.28	−1.61 ± 0.98	<0.01	0.43 ± 0.75	N.S	−0.45

Values are presented as mean ± standard deviation.
P value was evaluated by Mann–Whitney U test (vs. patent graft by CAG)
HEMS: HyperEye Medical System; ICG: indocyanine green; CAG: coronary angiography.

Table 3: Relationship of HEMS parameters between patent and abnormal grafts.

Among the TTFM parameters, there was a significant difference in the MF (21.44 ± 13.35 vs. 9.66 ± 4.61 ml/min, p<0.05) between patent and abnormal grafts. Among the HEMS parameter, there were significant differences in peak-I at the distal portion of the graft (226.1 ± 34.6 vs. 144.3 ± 8.0 grayscale), Ratio-I (1.04 ± 0.16 vs. 0.69 ± 0.25) and Ratio-max dI/dt (0.98 ± 0.28 vs. 0.49 ± 0.19) (p<0.05 for all) (Table

3). In ROC analysis, the cut-off value for each parameter was 152.35 gray scale (sensitivity 1.000, specificity 0.957, AUC 0.979) for peak-I at the distal portion of the graft, 0.711 (sensitivity1.000, specificity 0.979, AUC 0.993) for Ratio-I and 0.685 (sensitivity1.000, specificity 0.872, AUC 0.957) for Ratio- max dI/dt.

Abnormal ITA graft by postoperative CAG/ other type by HEMS

One ITA graft was determined as abnormal by postoperative CAG and was classified as other type by HEMS. The abnormality determined by postoperative CAG was occlusion of the graft. For this graft, TTFM data showed 19 ml/min MF, 1.7 PI, and 72% DF, whereas HEMS parameters showed decreased peak ICG fluorescence intensity at both mid and distal portions of the graft (less than 150 grayscale) and increased ratio of dI/dt (1.29). The statistical analysis was not completed because this group included one abnormal graft only (Table 3).

Discussion

TTFM and high-frequency epicardial ultrasound have been used as popular tools in CABG [15-24]. Likewise, ICG-AG has been commonly used for evaluating graft patency. Many reports in literature demonstrated the effectiveness of ICG-AG for CABG [1-5]. In Japan, the SPY system and HEMS have been used for CABG; however, quantitative analysis has not been a popular method because a better analysis software program is not yet available. Figure 1 shows current HEMS visual assessment. TTFM assessment showed the patency of the each ITA graft (Figure 1a-1c). We agreed the quality of the graft in Figure 1a, as a patent graft, and Figure 1d, as an occlusive graft image by using qualitative assessment only. However we were able to judge the quality of the graft in Figure 1b and 1c, intraoperatively. For Figure 1b case, we suspected that the flow volume of the ITA graft was lower than the LAD flow volume but we did not revise the graft intraoperatively. As a result, CAG showed the patency of the ITA graft. On the other hand, for Figure 1c case, we suspected that the flow volume of the ITA graft was decreased from the proximal portion to the distal portion, but we did not revise the graft intraoperatively. As a result, CAG showed the severe stsnosis of the ITA graft.

Quantitative assessment and reproducibility are important factors for a scientific study; therefore, we devised a model for quantitative analysis by ICG-AG.

The concept of quantitative analysis

Any software program can be produced and used for quantitative analysis with ICG-AG. When the background is not moving during image capture, changes in ICG fluorescence intensity at the ROI is easy to measure. However, a better image tracking software program does not exist in the real world. In a CABG model, the ROI on the graft is moving during image capture; therefore, it is difficult to measure changes in intensity at the ROI on the graft. To address this problem, we added two operations for the HEMS movie. These were as follows:

- Creation of image-stabilization movie using YouTube movie editor.
- Conversion to a spatiotemporal image by Image J.

In the current practice of using qualitative analysis alone, HEMS can detect an occluded graft as no ICG fluorescence intensity and suspect graft stenosis as a decreased ICG fluorescence intensity. These changes can be marginally induced by anatomical factors (e.g., graft stenosis, injury or poor quality of the anastomosis, etc.). On the other hand, moderate native coronary artery stenosis can have a preceding ICG perfusion compared with an in situ arterial graft. When flow volume is lower in a graft than in a native coronary artery, HEMS detects to and fro flow image on the anastomosis. These changes can be marginally induced by functional factors (e.g., difference in flow dynamics between graft and native coronary artery).

We hypothesized that irregularity of flow dynamics would be characteristic of graft flow-acceleration pattern. Although previously literature used the time elapsed from the fluorescence onset to half the maximum intensity (T1/2) as a parameter for the flow irregularity, it does not enhance the acceleration value of the flow because of graphical analysis method. For using parametrical analysis method, we have changed a raw ICG Fluorescence intensity curve to the 6-polynomial approximation curve, and we have obtained a first-derivative curve (acceleration curve) to determine the acceleration values.

Previously we reported new evaluation method of TTFM: we converted TTFM waveform to a polynomial approximation curve and the first derivative curve (flow-acceleration curve), and then a flow-acceleration value that was measured from the first derivative curve became a predictor of further graft failure [23,24]. Here we used same concept of the analysis method in this present study.

The relationship between HEMS parameters and CAG outcome

Many reports in literature demonstrated that severity of coronary artery stenosis, TTFM parameters, and severity of to and fro flow on TTFM were risk factors for further graft failure [19-24]. In the present study, we found major four types of the flow dynamics. Therefore we have compared the flow dynamics of the patent graft on CAG with that of the graft on CAG in each HEMS evaluation and we collected variables, such as native coronary artery stenosis, TTFM parameter, time delay with peak ICG fluorescence intensity acceleration (time delay with dI/dt), and ratio of maximum ICG fluorescence intensity acceleration between mid and distal portions of the graft (Ratio-max dI/dt), as risk factors for further graft failure.

As a result of overall data analysis, the TTFM parameters MF and PI, and the HEMS parameters peak-I value in the mid potion of the graft, time-delay with I, and time-delay with max dI/dt showed a significant difference. TTFM measured graft flow by a simple procedure, but it was not able to measure native coronary artery flow simultaneously. In this study, we considered that detection of the time interval between graft and native coronary artery flow was an advantage for intraoperative evaluation of flow dynamics. On the other hand, although Ratio with dI/dt was not a significant factor in the overall data analysis, it significantly varied between patent and abnormal grafts across all HEMS type, except in the other type.

According to the principle of flow dynamics, anatomical failure of a graft leads to down regulation of the intragraft flow volume from proximal to distal portion. Our results on decreased Ratio-max dI/dt suggested a tendency for anatomical graft failure (e.g., stenosis of the graft, stenosis on the anastomosis, etc.). The flow dynamics after CABG depends on the relationship between graft flow and native coronary artery flow as a functional factor. Furthermore, down regulation of intragraft flow volume is brought about by anatomical factors, such as stenosis/injury of the graft. Based on our results, we propose that use of both TTFM and ICG-AG is a better method for

intraoperative evaluation during CABG. Moreover, time delay with dI/dt may be a predictor of functional abnormality and the ratio-max dI/dt may be a predictor of anatomical abnormality.

Limitations of the Study

The limitations of this study were its retrospective nature and the small data set from a single center. If we have had the large data set, we performed multivariable analysis between CAG outcomes, TTFM and HEMS parameters. To increase statistical power, we should collect a larger data set in the future. In addition, we did not investigate the quality of the anastomosis intraoperatively because we did not have a high-frequency probe during this study period.

Conclusion

We produced a new image analysis method using movie stabilization and spatiotemporal image analysis with HEMS during CABG. Our results suggested that the relationship of the change in ICG fluorescence intensity acceleration value between mid and distal portions of the graft may be a predictor of further graft failure. A better image tracking software program that can measure changes in ICG fluorescence intensity should be developed.

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None

Conflict of interest

None of the authors have any conflicts of interest related to this study.

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