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Clinical Research

Initial Experience with Epicardial Ultrasound Scanning in Coronary Artery Bypass Grafting

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Background: The benefits of epicardial ultrasound scanning (EUS) in coronary artery bypass grafting (CABG) have not yet been established. The aim of this study was to evaluate the usefulness of EUS in CABG, including in the assessment of the quality of distal anastomoses, the identification of epicardial target vessels, and the evaluation of any graft issues other than the distal anastomoses.
Methods: Fifty-three patients undergoing CABG were enrolled between March 2018 and February 2019. Intraoperative EUS was performed along with transit-time flow measurement (TTFM). Graft evaluations were performed early (shortly after surgery) and 1 year after surgery for 53 (100%) and 47 (88.7%) patients, respectively.
Results: EUS was applied to assess the quality of all distal anastomoses, 32 target vessels, and 2 conduit trunks. Insufficient TTFM findings were obtained for 18 grafts. However, graft revision was performed for only 3 distal anastomoses; based on the EUS findings, the remaining 15 sites were not revised. The early and 1-year overall graft patency rates were 100% (141 anastomoses) and 96.1% (122 of 127 anastomoses), respectively. All 15 of the distal anastomoses that were not revised despite insufficient TTFM results were patent at the 1-year mark.
Conclusion: The routine application of EUS in CABG could be beneficial by confirming the quality of surgery and reducing unnecessary procedures.

Keywords: Coronary artery disease, Coronary artery bypass, Ultrasonography, Vascular patency

Introduction

Due to its favorable long-term outcomes, coronary artery bypass grafting (CABG) has been widely used as the standard of treatment for patients with ischemic heart disease [1]. The clinical and prognostic benefits of CABG are largely determined by the graft patency rates after surgery, and various tools have been introduced to detect intraoperative graft failure and to improve graft patency [2,3]. Among these, transit-time flow measurement (TTFM), a non-invasive approach, has been widely used to evaluate the flow patterns in bypass grafts [4]. However, the definitive cut-off values of TTFM remain elusive, and the low sensitivity of TTFM has resulted in a high false-negative detection rate for graft problems [5,6].

Epicardial ultrasound scanning (EUS) has been introduced to obtain additional information about bypass grafts by directly evaluating the anastomotic sites. Unlike TTFM, EUS provides visual imaging of the vessel lumen and flow inside the vessels using color Doppler ultrasound [7]. Therefore, EUS can be applied to native coronary arteries and graft bodies as well as distal anastomoses [8]. However, the benefits of this tool have not yet been established. Therefore, the present study was conducted to evaluate and describe our initial experience with the routine application of EUS along with TTFM in daily CABG practice.

Methods

Patient characteristics

The study protocol was reviewed by the institutional re-

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Table 1. Preoperative characteristics and risk factors (N=53)

Characteristic	Value
Age (yr)	65.6±10.7
Male	39 (73)
Society of Thoracic Surgeons score (%)	1.04
Risk factors	
History of smoking	27 (50.9)
Overweight (body mass index >25 kg/m^2)	24 (45.3)
Diabetes mellitus	25 (47.2)
Hypertension	33 (62.3)
Dyslipidemia	22 (41.5)
History of stroke	4 (7.5)
Chronic obstructive pulmonary disease	3 (5.7)
Chronic kidney disease	13 (24.5)
Left ventricular dysfunction (ejection fraction <35%)	4 (7.5)
Emergency or urgent	8 (15.1)
Acute coronary syndrome	35 (66.0)
Type of coronary artery disease	
Left main disease	10 (18.9)
3-Vessel disease	23 (43.4)

Values are presented as mean±standard deviation or number (%), unless otherwise stated.

Table 2. Operative data (N=53)

Variable	No. (%)
Isolated CABG	48 (90.1)
Primary off-pump CABG	41 (77.4)
On-pump beating CABG	3 (5.7)
Redo off-pump CABG	1 (1.9)
Robot-assisted MIDCAB	3 (5.7)
Concomitant operation	5 (9.4)
Aortic valve replacement	3 (5.7)
Redo-tricuspid valve replacement	1 (1.9)
Repair of post-infarct ventricular septal defect	1 (1.9)
No. of distal anastomoses	141
Left ITA	58 (41)
Right ITA	69 (49)
Saphenous vein	14 (10)

CABG, coronary artery bypass grafting; MIDCAB, coronary artery bypass grafting; ITA, internal thoracic artery.

view board of Seoul National University Hospital and approved as a minimal-risk retrospective study (IRB approval no., 1904-125-1028) that did not require individual consent. Between March 2018 and February 2019, a total of 57 patients underwent isolated or concomitant CABG performed by a single surgeon. Four patients were excluded because EUS was unavailable during surgery; therefore, 53 patients underwent EUS evaluation during CABG and were enrolled in the present study. The mean age at the time of operation was 65.6±10.7 years, and 14 patients (26.4%) were female. Hypertension (n=33, 62.3%) and diabetes mellitus (n=25, 47.2%) were the most common comorbidities (Table 1).

Operative data and grafting strategy

Isolated CABG was performed in 48 patients, with off-pump and on-pump beating CABG performed in 44 and 4 patients, respectively. The concomitant procedures in the other 5 patients included aortic valve replacement (n=3), tricuspid valve replacement (n=1), and post-infarct ventricular septal defect repair (n=1). The left internal thoracic artery (ITA) was used in the CABG procedure for all but 1 patient, in whom the right ITA was used only for the revascularization of the right coronary artery territory. The second conduits were used as Y-composite grafts for 40 patients (specifically, the right ITA and the saphenous vein [SV] for 32 and 8 patients, respectively). The total number of distal anastomoses was 141. The grafting strategies during the study period were as follows: (1) an aortic off-pump coronary artery bypass using composite grafts based on the *in-situ* left ITA whenever multiple distal anastomoses were required, (2) harvesting of the ITA with a skeletonization technique, and (3) no-touch SV harvesting from the lower leg. Whenever needed, the left anterior descending coronary artery (LAD) territory was revascularized first using the left ITA. Sequential anastomoses of the diagonal branch and LAD were performed using the left ITA if anatomically feasible. The left circumflex coronary artery territory was then revascularized, after which the right coronary artery territory was revascularized using the sequential technique. The median number of distal anastomoses was 3 (interquartile range, 2 to 4) (Table 2).

Intraoperative application of transit-time flow measurement

Intraoperative TTFM was used to assess graft function. All anastomoses were assessed using TTFM after each distal anastomosis was made. A low flow rate (<15 mL/min) and high pulsatility index (>3 and >5 in the left and right coronary artery territories, respectively) were considered abnormal TTFM findings [9].

Intraoperative epicardial ultrasound scanning

Intraoperative EUS was routinely performed with the VeriQ C system (Medi-Stim AS, Oslo, Norway). The application of EUS included (1) the assessment of the quality of the distal anastomosis, (2) the identification of the epicar-

dial target vessels, and (3) the evaluation of any graft issues other than the distal anastomosis. All distal anastomoses were measured with TTFM and EUS immediately after completing each anastomosis. Because the quality of the EUS image was very sensitive to cardiac motion, EUS was performed before the stabilizer was removed. The probe was applied to the bypass conduit in the longitudinal and perpendicular directions. When the body or arms of the stabilizer interfered with the application of the probe, the stabilizer was not removed; instead, it was moved next to the anastomosis site to minimize the motion of the heart.

When abnormal findings were detected via TTFM, the decision to revise the anastomosis was made based on the EUS findings. Poor quality of the distal anastomosis was indicated by (1) stenosis of the anastomotic site and (2) the presence of any abnormal tissue such as atheromatous plaque or a tissue tag in the middle of the anastomotic site. Poor EUS results included a lack of visible color flow inside the graft lumen and poor quality of the distal anastomosis.

Evaluation of clinical outcomes

Early mortality was defined as any death within 30 days after surgery or during hospitalization for surgery. Postoperative atrial fibrillation was defined as any short runs of atrial fibrillation on 24-hour continuous electrocardiographic telemonitoring prior to discharge. Respiratory complications included postoperative pneumonia or more than 48 hours of prolonged ventilator support. Postoperative acute kidney injury was defined as an increase in the serum creatinine level of greater than 50% of the preoperative value or the need for renal replacement therapy. Perioperative myocardial infarction was diagnosed based on 2 or more of the following abnormalities: an elevated peak serum creatine kinase isoenzyme level, the appearance of new Q waves on the electrocardiogram, and newly-developed regional wall motion abnormalities on the postoperative echocardiogram. Low cardiac output syndrome was defined as the need for mechanical or inotropic support to maintain a systolic blood pressure >90 mm Hg even after the correction of reversible factors.

Evaluation of graft patency

Early postoperative graft angiograms were performed for all patients at 1.4±1.0 days after surgery. Additionally, graft patency was evaluated at 1 year postoperatively according to a routine postoperative evaluation protocol at our institution. A total of 47 patients (88.7%) underwent 1-year graft evaluation at 12.4±2.2 months after surgery using coronary angiography (n=14) or multidetector computed tomography angiography (n=33). A total of 127 distal anastomoses were evaluated at 1 year after CABG. The coronary angiograms were reviewed by 2 specialists, and the multidetector computed tomography angiograms were also reviewed by 2 specialists. Each pair of specialists reached a consensus regarding the graft patency.

Results

Applications of epicardial ultrasound scanning

The applications of EUS in this study were as follows: (1) The quality of all 141 distal anastomoses was evaluated. A total of 123 distal anastomoses with normal TTFM results also exhibited good EUS findings. Abnormal TTFM findings (low flow or high pulsatility index) were found in 18 distal anastomoses [9]. Poor EUS results were found in 3 of these 18 distal anastomoses; no color flow was detected in 2 anastomoses, and an abnormal flow leak to the free space outside the native coronary artery was found in the other anastomosis, in which the epicardium was severely fibrotic. TTFM showed acceptable flow patterns after revision of these 3 anastomotic sites, and patency was confirmed using EUS (Fig. 1). Based on the EUS findings, revision of the distal anastomosis was not performed for the other 15 cases (Fig. 2). The abnormal TTFM results were false positives for 15 of 18 cases; therefore, the false-positive detection rate was 83.3%. (2) EUS was used to evaluate 32 target epicardial arteries in 30 patients to identify the appropriate anastomosis sites. The target vessels for revascularization were changed to adjacent vessels in 5 patients based on the EUS findings of a small-caliber atherosclerotic lumen (<1 mm, n=2) and an intramyocardial course across the entire vessel length (n=3). (3) Two patients exhibited gross hematoma in the left ITA trunk. These conduits were evaluated using EUS to verify the possibility of graft trunk dissection. Subsequently, these conduits were used without manipulation because no evidence of graft dissection was found.

Early clinical outcomes

The early mortality rate was 1.9% (1 of 53 patients). This patient underwent minimally invasive direct CABG because stenosis of the proximal LAD was detected during the preoperative evaluation for peripheral vascular surgery. The patient developed postoperative ischemic colitis and

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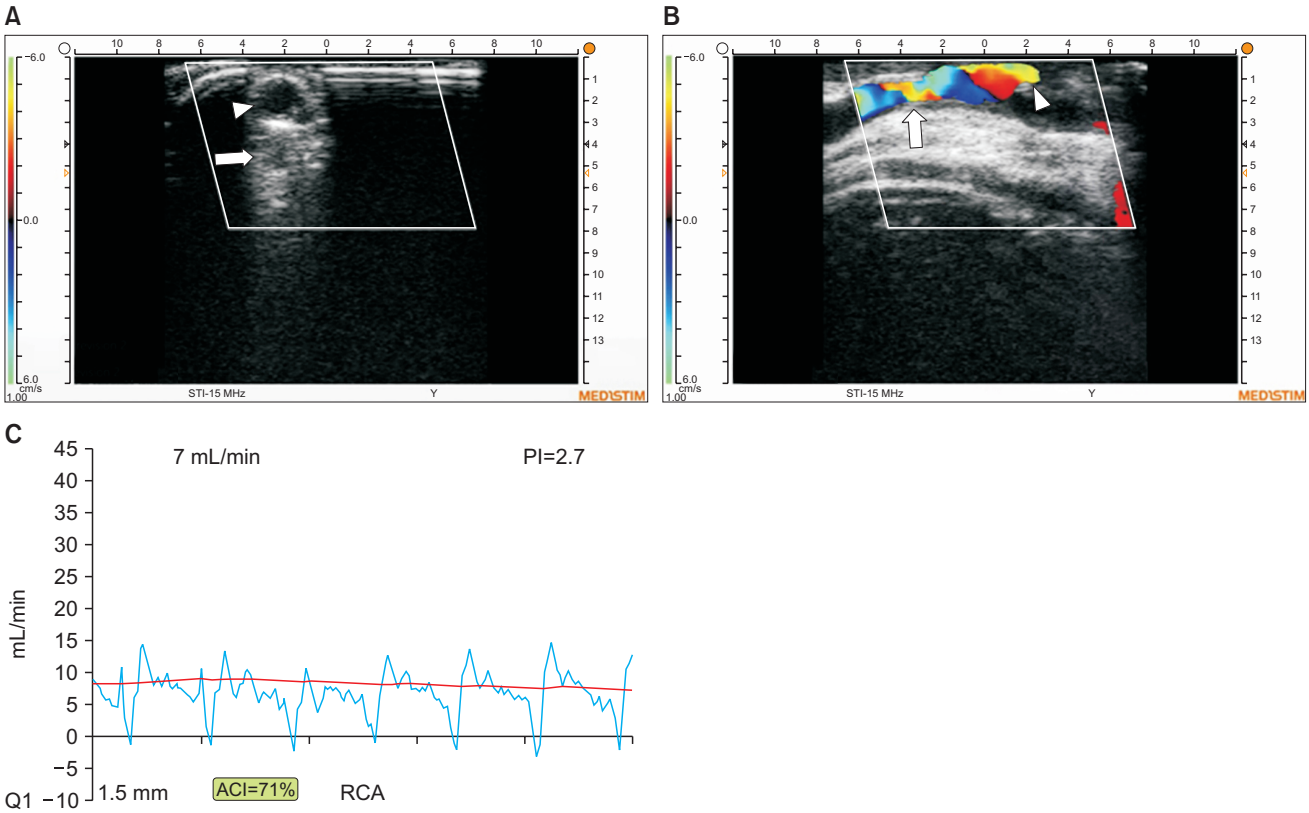

Fig. 1. TTFM and EUS findings in a patient requiring graft revision of the right internal thoracic artery (arrow head) to the distal RCA (arrow). After the initial anastomosis, the TTFM flow was 0 mL/min, and (A) the EUS showed no color flow in the graft lumen. After revision, (B) color flow was detected in the EUS with a widely patent anastomosis site, and (C) the PI of the TTFM was sufficient, although the flow rate was relatively low at 7 mL/min. TTFM, transit-time flow measurement; EUS, epicardial ultrasound scanning; RCA, right coronary artery; PI, pulsatility index; ACI, acoustic coupling index.

died on the ninth postoperative day. Overall, postoperative complications included new-onset atrial fibrillation (n=13, 24.5%), respiratory complications (n=3, 5.7%), acute kidney injury (n=2, 3.8%), and low cardiac output syndrome (n=2, 3.8%) (Table 3).

Early and 1-year graft patency

All grafts except 1 were identified as patent on early postoperative angiograms (Table 4). One left ITA graft, which was used to revascularize the LAD, was marked as occluded on the postoperative angiogram on the first operative day. A redo sternotomy procedure was performed to explore the graft on the same day. However, the procedure was finished only after confirming the patency of the flow of the left ITA to the LAD based on the EUS findings. The patency of the graft was confirmed again on the 1-year graft angiogram (Fig. 3). The overall 1-year patency rate was 96.1% (122 of 127 distal anastomoses) (Table 4). The 1-year graft evaluation revealed patient grafts in all 15 distal anastomoses that, based on the EUS findings, were not revised despite poor TTFM data. Additionally, 2 of the 3 grafts that were revised based on the EUS findings were evaluated at the 1-year mark and confirmed to be patent (Table 5).

Discussion

In the present study, we demonstrated that the routine application of EUS along with TTFM may be safe and efficient in CABG. The favorable long-term results of CABG are attributable to graft patency, and various methods of intraoperative assessment of graft patency have been used to prevent early graft failure [2]. Among these methods, TTFM has been widely used for the functional assessment of grafts because of its non-invasive nature. However, TTFM has several limitations, such as its low sensitivity (resulting in a high false-negative detection rate) and its

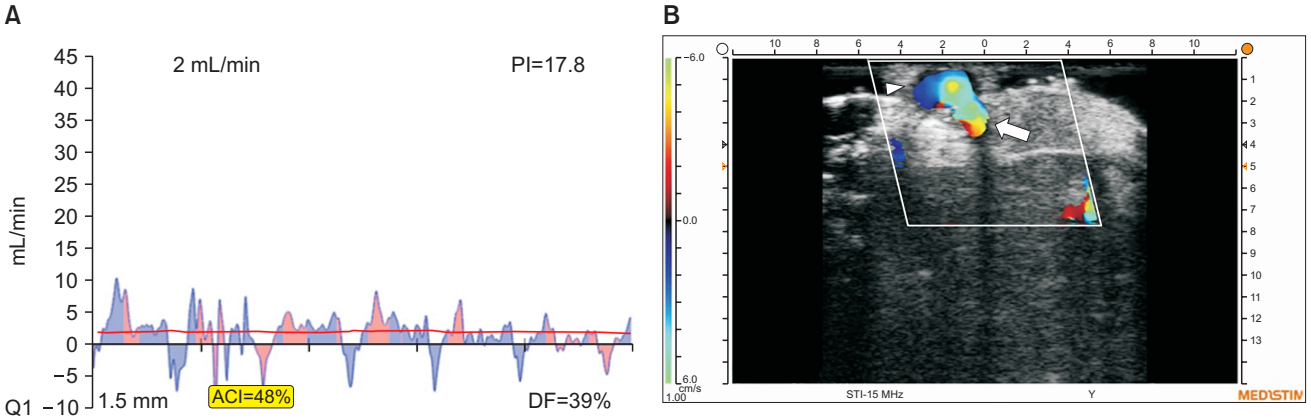

Fig. 2. Evaluation of the distal anastomosis site of the saphenous vein (arrow head) to the posterior descending coronary artery (arrow) in a 68-year-old man. (A) The transit-time flow measurement shows a high PI and a low flow rate. However, (B) epicardial ultrasound scanning demonstrates a patent anastomotic site with color flow inside the lumen. PI, pulsatility index; ACI, acoustic coupling index; DF, diastolic filling.

Table 3. Early clinical outcomes (N=53)

Variable	No. (%)
Mortality	1 (1.9)
Complications	
Postoperative atrial fibrillation	13 (24.5)
Respiratory complication	3 (5.7)
Acute kidney injury	2 (3.8)
Stroke	0
Postoperative myocardial infarction	0
Low cardiac output syndrome	2 (3.8)
Reoperation for bleeding	2 (3.8)
Superficial wound complication	1 (1.9)

Table 4. Early and 1-year angiographic patency rates of bypass grafts

Graft	Patency rate
Early results (n=53)	
Overall	100 (141/141)
Left ITA	100 (59/59)
Right ITA	100 (68/68)
Saphenous vein	100 (14/14)
One-year results (n=47)	
Overall	96.1 (122/127)
Left ITA	96.3 (52/54)
Right ITA	96.6 (57/59)
Saphenous vein	92.9 (13/14)

Values are presented as % (number/total number).
ITA, internal thoracic artery.

lack of definitive cut-off values [5].

EUS is another tool that can be used during CABG. One of its advantages is that it can provide visual imaging in addition to color flow result. Intraoperative imaging of the anastomosis site provides objective data, resulting in a more accurate assessment of graft quality. However, although intraoperative EUS was introduced in the 1980s, it has not been widely used due to its large probe size. Recently, the increased availability of smaller probes and other functional information has allowed for the EUS-based evaluations of small vessels, such as the coronary artery and bypass conduit [10,11]. Additionally, EUS enables scanning of the entire area of the heart, including the posterior aspect, where space is limited. However, the benefits of the routine use of EUS in CABG have not been well-established, and the adoption of EUS in Korean institutions remains limited.

In this present study, intraoperative EUS with TTFM was routinely performed to evaluate all distal anastomoses. Abnormal TTFM findings were observed in 18 of 141 distal anastomoses. Of these sites, only 3 anastomoses were considered abnormal according to the EUS findings, and they were subsequently revised. The abnormal TTFM results for the remaining 15 of the 18 cases were false positives; therefore, the false-positive detection rate of TTFM in this study was 83.3%, which was quite high. Another study showed a similarly high false-positive detection rate of TTFM (94.8%; 37 of 39 cases) [10]. The difference in the false-positive detection rates of TTFM and EUS originates from the mechanism of each method. TTFM is based on the transmission of 2 ultrasound beams. Even in a patent graft, TTFM can yield poor results due to the presence of backward flow, the impact of competitive flow, or the inappropriate positioning of the probe [10]. In addition, factors such as the measurement of graft flow when the heart

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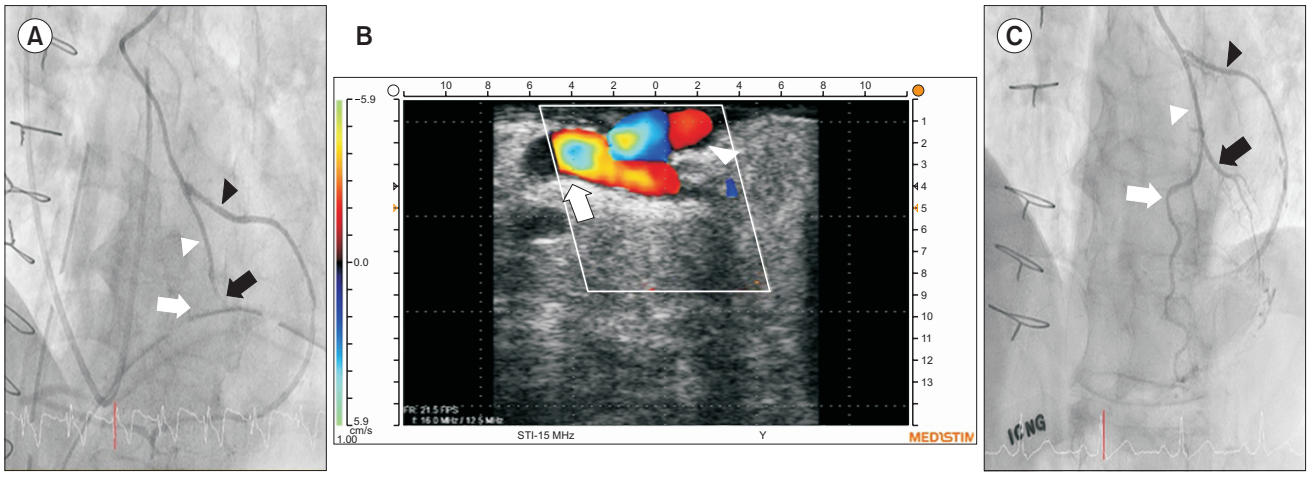

Fig. 3. Postoperative graft evaluations of a 66-year-old man who underwent coronary artery bypass grafting including the LITA (white arrow head) to the diagonal (black arrow) and LAD (white arrow) as the sequential anastomosis and the right internal thoracic artery (black arrow head) to the obtuse marginal branch and posterior descending artery as a Y-composite graft. (A) One-day angiography revealed a patent diagonal anastomosis; however, the LITA-to-LAD anastomosis was not assessed during graft angiography or native coronary evaluation. (B) Re-exploration was done on the same day as angiography, and the epicardial ultrasound evaluation demonstrated a patent anastomosis with color flow inside the lumen, from the LITA to the LAD. (C) One-year graft angiography also revealed patent flow of the LITA to the LAD. LITA, left internal thoracic artery; LAD, left anterior descending coronary artery.

Table 5. One-year angiographic patency rates of bypass grafts divided by intraoperative TTFM and EUS findings

	Good EUS findings	Poor EUS findings
Good TTFM results	95.5 (105/110)	-
Poor TTFM results	100 (15/15)	100 (2/2)[a]

Values are presented as % (number/total number).
TTFM, transit-time flow measurement; EUS, epicardial ultrasound scanning.
[a]Grafts were revised intraoperatively based on the TTFM and EUS findings.

is lifted to complete the lateral and inferior wall vessel anastomoses, a size mismatch between the probe and the SV diameter, and the perivascular tissue of the no-touch SV can interfere with the accuracy of TTFM readings. In contrast, EUS is based on the Doppler effect and provides a visualization that can be useful for evaluating the patency of distal anastomoses regardless of the position of the heart, the diameters of the conduits, and the presence of perivascular tissue.

The overall 1-year patency rate of 96.1% in the present study is consistent with previously-published results [12-14]. The 1-year angiography results demonstrated that all of the grafts with suboptimal patterns on intraoperative TTFM but satisfactory EUS findings were patent. This suggests that the use of EUS in addition to other graft evaluation tools may help to avoid the unnecessary revision of anastomotic sites during CABG.

Because EUS provides visual imaging of the vessel lumen and flow inside the vessels using color Doppler ultrasound, it can be applied to the native coronary arteries and graft body to identify atherosclerotic changes or vessel dissection [7,8,15]. When epicardial target vessels run an intramyocardial course or have severe calcification, it is difficult for surgeons to choose a safe and efficient distal anastomosis site based on preoperative angiography or intraoperative palpation. In such cases, appropriate anastomosis sites could be determined with EUS, and unnecessary coronary artery dissection could be avoided. In the present study, 30 epicardial target vessels were evaluated to identify optimal target anastomosis sites. In addition, the presence of dissection in the left ITA trunk that could not be clearly evaluated with other tools was assessed in 2 patients.

The present study had several limitations. First, it was a retrospective observational study conducted by a single surgeon. Second, the number of enrolled patients was relatively small. Third, a comparative study could not be performed because EUS was routinely used during the study period whenever it was available.

In summary, EUS allows for the visual evaluation of the quality of target vessels, conduits, and anastomosis sites. Because the application of EUS along with TTFM ensures a better-quality assessment and reduces unnecessary intraoperative procedures, it could improve the surgical outcomes of CABG. As such, the routine application of EUS could be beneficial in CABG, but further study is needed.

Conflict of interest

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

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