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Intraoperative Transesophageal Echocardiography for Coronary Artery Assessment

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Background: In surgical aortic valve replacement (SAVR), coronary arteries are routinely assessed by transesophageal echocardiography (TEE) to prevent undesirable complications. This study evaluated the capabilities and pitfalls of TEE assessment.

Methods and Results: Of 147 consecutive SAVR patients undergoing aortic stenosis, the TEE records for 130 patients, in which the procedures were conducted by a single examiner, were analyzed retrospectively regarding data acquisition and the accuracy of detecting an anomalous origin, high or low takeoff, ostial diameter, and short left main truncus (LMT). The left and right coronary arteries could be visualized in every patient. A left coronary ostium >5 mm was found in 33 patients (25.4%). TEE revealed an anomalous origin in 2 patients (1.5%) that had not been diagnosed, but missed it in another patient. High takeoff was noted in 11 patients (8.3%), often associated with aortic disease necessitating aortic repair. In one such patient, occlusion of the right coronary artery was detected, necessitating coronary revascularization. Short LMT was found in 15 patients (11.8%) but misdiagnosed due to artifact in 1. During selective cardioplegia, malperfusion of the left anterior descending artery due to deep cannula placement was detected.

Conclusions: TEE provides fairly accurate assessment in SAVR, including detection of undiagnosed pathologies or pitfalls related to coronary arteries, although misdiagnosis due to artifacts should be kept in mind.

Key Words: Aortic valve replacement; Coronary arteries; Transesophageal echocardiography

The outcomes of surgical and transcatheter aortic valve replacement (SAVR and TAVR, respectively) in Japan have improved recently, with 30-day mortality rates of 1.9% and 1.2%, respectively.[1] However, in the coming TAVR era, SAVR may be indicated for more complicated cases of patients at much higher risk who are elderly, frail, or have comorbidities but are not eligible candidates for TAVR because of severe aortic disease or a small aortic annulus. It is mandatory that all measures are taken to avoid worse surgical outcomes in such patients. One practical means of achieving best possible outcomes is to eliminate "preventable issues", as in the case of a patient with a severely calcified coronary ostium that developed dissection in the left main truncus (LMT) following selective cardioplegia (**Figure 1**). Despite coronary artery-related adverse events having a major effect on SAVR,[2–7] coronary angiography (CAG) and computed tomography (CT) are not feasible for on-site diagnosis and appropriate decision making during surgery. Thin-slice contrast-enhanced CT, which is routinely acquired before TAVR, may be helpful in predicting the risk of coronary issues. However, many elderly SAVR patients, particularly those with chronic kidney disease, only undergo CT scans without contrast. This has become more frequent as the population has continued to age, particularly at Kochi Medical School Hospital, which is located outside major Japanese conurbations. We have addressed this problem in 2 ways: (1) by devising a perfusion cannula that is universally applicable for a diseased coronary ostium;[8] and (2) by performing routine intraoperative assessment of the coronary arteries by transesophageal echocardiography (TEE).

TEE visualization of the coronary arteries was first reported in 1988.[9,10] Since then, it has been used to diagnose anomalous origins,[11–13] detect coronary artery obstruction during difficult weaning from cardiopulmonary bypass (CPB),[14,15] and to develop a surgical strategy in the presence of ostial lesions.[16,17] However, to the best of our knowledge there are no reports in the literature documenting routine intraoperative TEE assessment of coronary arteries with a specific focus on safety in SAVR. Therefore, in the present study we retrospectively analyzed our TEE records to clarify the capabilities, limitations, and pitfalls of TEE assessment to serve as the first step in further refining intraoperative strategies in SAVR for the coming era.

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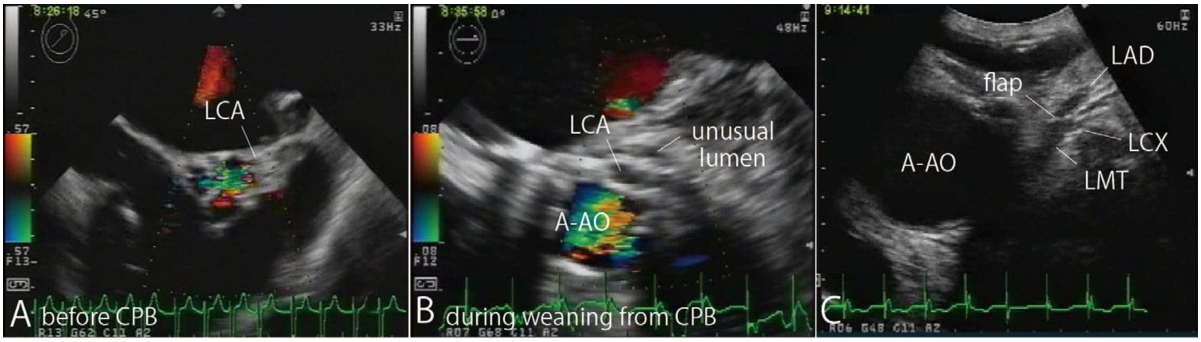

Figure 1. Transesophageal echocardiograms and epicardial ultrasonography of intraoperative dissection in the left main truncus (LMT). (**A**) Intact LMT before cardiopulmonary bypass (CPB). (**B**) An unusual lumen was observed, but LMT flow became undetectable. A-AO, ascending aorta. (**C**) A flap occluded the left anterior descending artery (LAD). LCX, left circumflex artery.

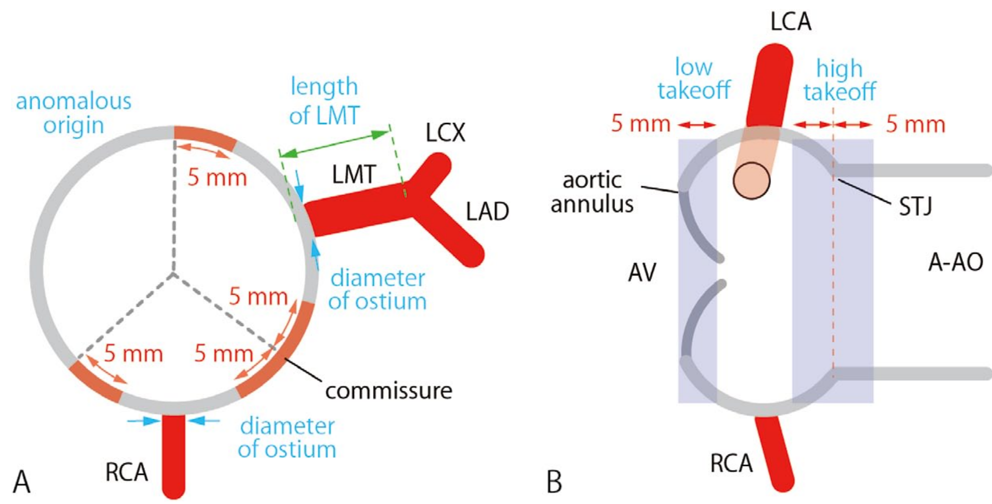

Figure 2. Schematic diagrams showing the criteria for transesophageal echocardiography (TEE) findings and measurements. (**A**) Short-axis view of aortic valve (AV). Anomalous origin was identified and the length of the left main truncus (LMT) and the diameter of the left and right coronary arteries (LCA and RCA, respectively) were measured. LAD, left anterior descending artery; LCX, left circumflex artery. (**B**) Long-axis view of the AV. Low and high takeoff was examined with reference to the aortic annulus and sinotubular junction (STJ). A-AO, ascending aorta.

Methods

Patients

Of the 147 consecutive SAVR procedures for aortic stenosis performed at Kochi Medical School Hospital between January 2012 and March 2018, 130 in which a single examiner (K.O.) performed the TEE assessment, were analyzed retrospectively. Of the 130 patients, 52 were men (40.0%) and the age range of the patient cohort was 48–90 years (mean [±SD] 77.0±7.8 years), including 57 octogenarians (43.8%). Concomitant procedures were conducted in 67 patients (51.5%), including coronary artery bypass grafting (CABG), mitral valve replacement, ascending aorta replacement, tricuspid valvuloplasty, maze procedures, debranching bypass for subsequent stent grafting, ligation of the left atrial appendage, and closure of the patent ductus arteriosus in 48, 10, 7, 7, 4, 2, 1, and 1 patients, respectively. Clinical data were collected from the database, medical charts, and records stored on the server at Kochi Medical School Hospital.

This study was approved by the Kochi Medical School Ethics Committee (Approval no. 30-55).

TEE Procedure

After induction of anesthesia, routine TEE follow-up for SAVR was performed using iE33 and X7-2t machines (Philips Electronics, Amsterdam, Netherlands). This follow-up included evaluation of cardiac function and aortic characteristics, as well as measurement of the dimensions of the aortic annulus and sinotubular junction (STJ). Next, the left and right coronary arteries (LCA and RCA, respectively) were visualized in mid-esophageal (ME) aortic valve (AV) short- and long-axis (SAX and LAX, respectively) views to assess anomalous origin, low or high

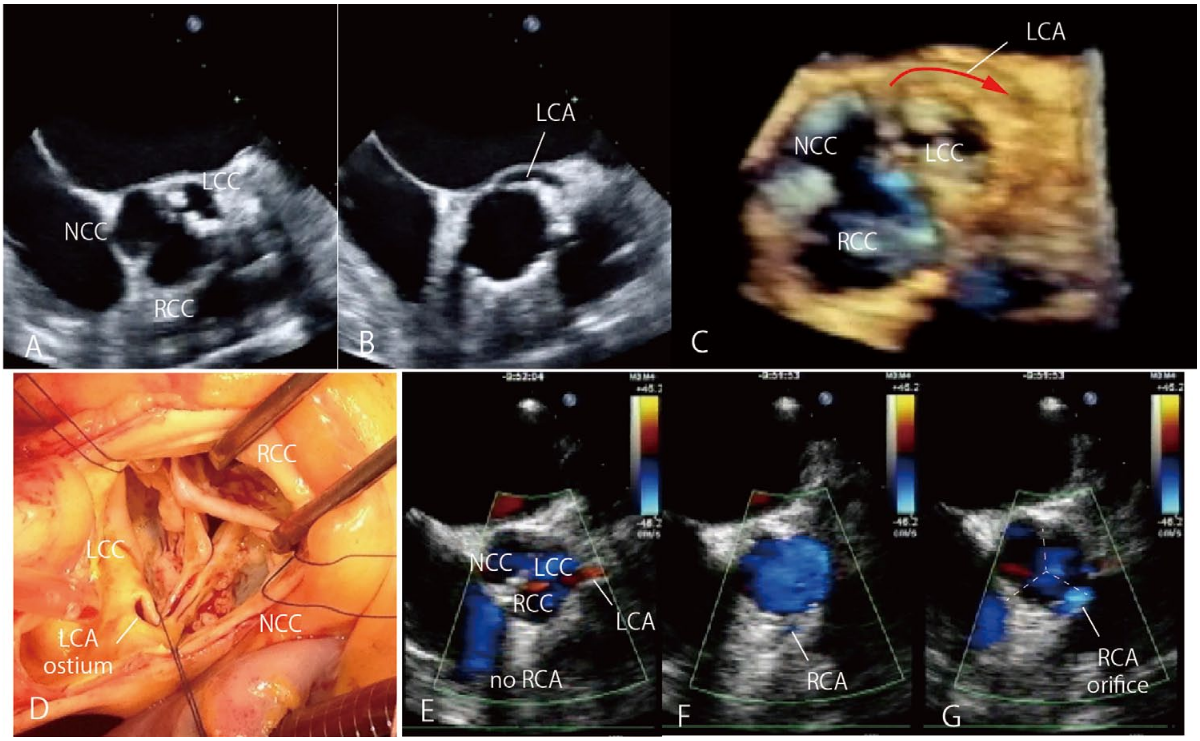

Figure 3. Anomalous origin of the right and left coronary arteries (RCA and LCA, respectively). (**A**–**D**) Anomalous origin of the LCA in Patient 35. The orifice is adjacent to the commissure between the non-coronary and left coronary cusps (NCC and LCC, respectively). RCC, right coronary cusp. (**E**–**G**) Anomalous origin of the RCA at the commissure between the RCC and LCC in Patient 124.

takeoff, coronary artery diameter, LMT length, and other findings potentially related to adverse events. After valve replacement, TEE assessment was performed to evaluate prosthetic valve function, peri- and transvalvular leakage, coronary artery perfusion, and cardiac performance. Basically, an ultrasound frequency band of "G" (3.5–5 MHz) was used with the highest B gain setting without causing background noise. A 2-dimensional mode, including xPlane mode, was primarily used to visualize the coronary arteries, whereas a 3-dimensional (3D) mode was used if specific assessment was needed. When coronary perfusion was assessed in color Doppler mode, the B gain was decreased and a velocity range of 15 to 30 cm/s was used with the highest color gain without causing background noise. If a flow signal was undetectable in the coronary artery even at a low velocity range, then epicardial ultrasonography (L15–7io, 15 MHz, Philips Electronics Co., Amsterdam, Netherlands) was used. Any TEE finding that was considered to be unusual was communicated to the surgeons, anesthesiologists, and perfusionists to discuss strategies.

TEE Measurements and Definitions

Because of the limited amount of time for TEE assessment, the TEE views were recorded on the server during surgery, with minimal on-site measurements. The TEE findings were reviewed and every measurement was made retrospectively by importing the recorded image to a personal computer and analyzing the captured images with graphics software (CANVAS 11; ACD Systems of America, Miami, FL, USA) using the scale in each image for calibration.

TEE measurements of LMT length and RCA/LCA diameter were validated by comparison with values measured using CAG images. The left anterior oblique caudal view (spider view) was primarily used to measure LMT length, whereas the left anterior oblique (60°) and right anterior oblique (30°) views were used to measure RCA and LCA diameters, respectively. Because no definite criteria for TEE assessment have been reported in the literature, we arbitrarily set the criteria for this study as shown in **Figure 2**. The coronary origin was defined as anomalous if it was located within 5 mm of the commissure in the ME AV SAX view. Low or high takeoff of the coronary artery was assessed in the ME AV LAX view; the former was defined as within 5 mm from the annulus, whereas the latter was defined as within 5 mm below or above the STJ. The length of the LMT was measured in the ME AV SAX view as the distance from the coronary ostium to the bifurcation of the left anterior descending artery (LAD) and left circumflex artery (LCX), and was defined as short when it was <5 mm.

Data are expressed as the mean ± SD.

Results

Two patients (1.5%) died within 30 days of the procedure. One was a 90-year-old woman who underwent emergency SAVR for severe aortic stenosis with a small annulus and

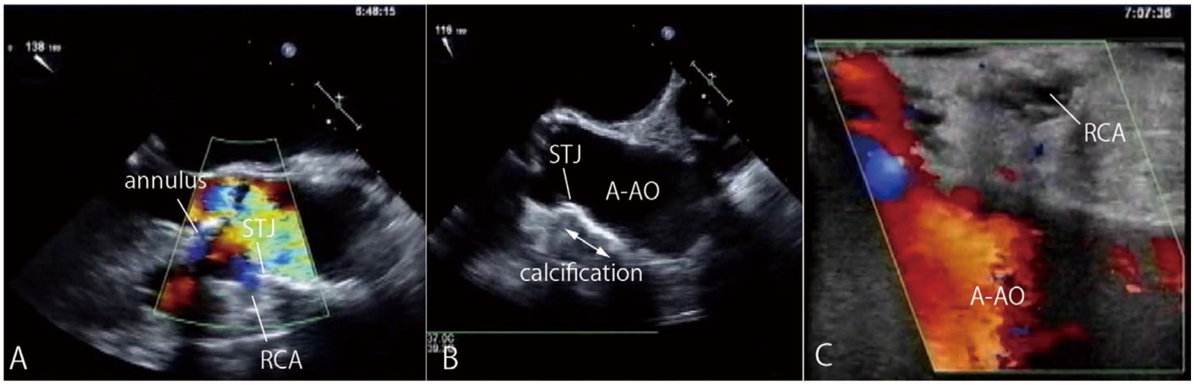

Figure 4. High takeoff of the right coronary artery (RCA). (**A**) The origin is just below the sinotubular junction (STJ). (**B**) Marked calcification of the ascending aorta (A-AO) above the STJ. (**C**) Epicardial ultrasonogram of RCA without detectable blood flow.

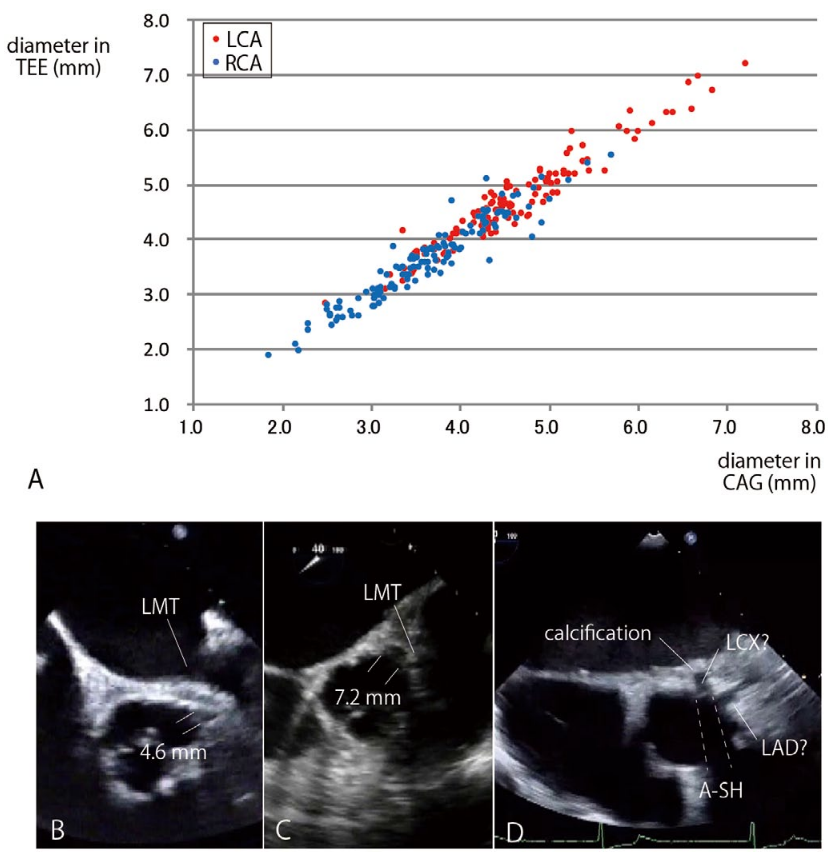

Figure 5. Measurement of the diameter of the right and left coronary arteries (RCA and LCA, respectively). (**A**) Correlation between the diameter measured on coronary angiograms (CAG) and on transesophageal echocardiograms (TEE). (**B**) An average size LCA ostium. LMT, left main truncus. (**C**) The largest LCA ostium in the present series. (**D**) Acoustic shadows adjacent to the LMT were considered to be an additional coronary artery in Patient 116. A-SH, acoustic shadow; LAD, left anterior descending artery; LCX, left circumflex artery.

advanced cardiac failure following extraction of an infected pacemaker. The second patient was a 70-year-old woman with suspected LCA malperfusion and a patent LCA ostium. No TEE complications were encountered.

Visualization of the Coronary Arteries

Visualization of the LCA and RCA was confirmed in the TEE records in either or both ME AV SAX and LAX views in every patient, although the RCA was not always identified in the operating theater because of interference from the acoustic shadow and side lobe artifacts caused by AV calcification, the STJ, and aorta. Visualization of the RCA necessitated meticulous maneuvering of the TEE probe to find an appropriate route for ultrasound penetration that was not hindered by an acoustic shadow, including upward or downward and lateral bending associated with probe depth. In the TEE records, the RCA was identified by the flow signal or echo-free lumen that opened to the

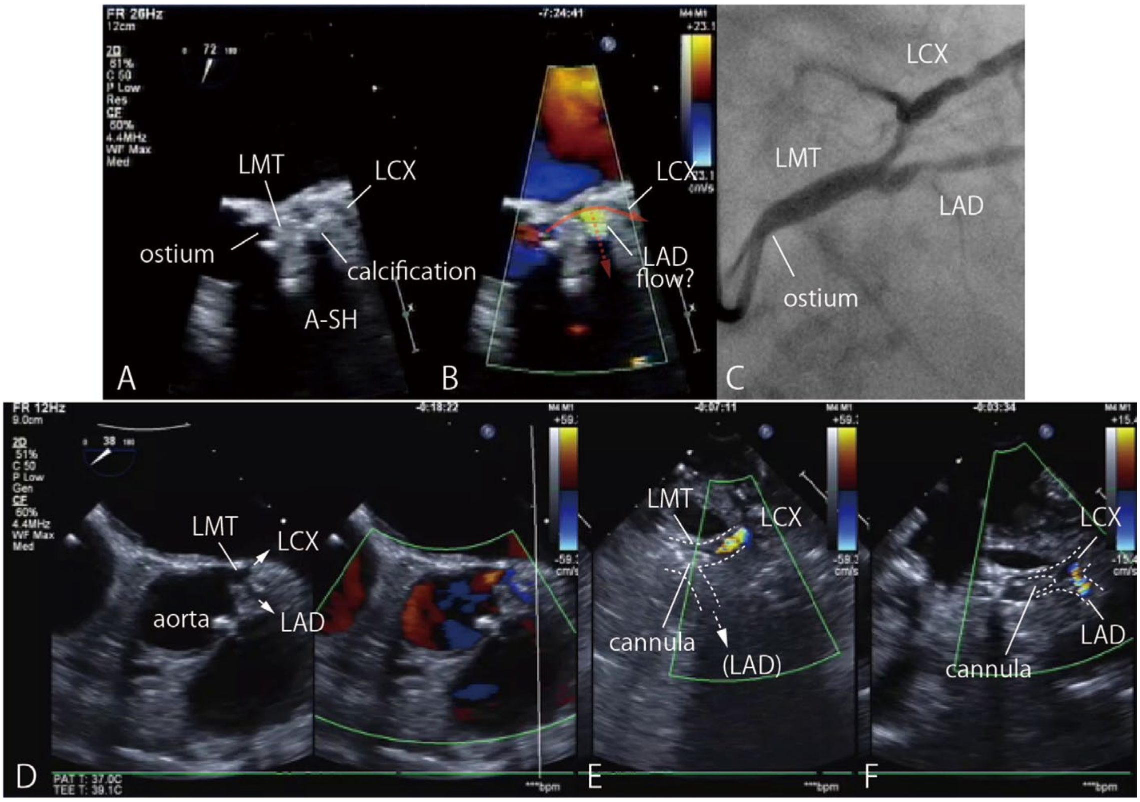

Figure 6. Assessment of a short left main truncus (LMT). (**A**) Misdiagnosed short LMT in Patient 29. A-SH, acoustic shadow; LCX, left circumflex artery. (**B**) An accelerated flow signal was seen in the left anterior descending artery (LAD). (**C**) Coronary angiogram showing that the LMT is not short. (**D**) A short LMT visualized in the short-axis view of the aortic valve in Patient 130. (**E**) Malperfusion during selective cardioplegia. A flow signal was not detected in the LAD. (**F**) After the cannula was replaced, flow was detected in both arteries.

right coronary sinus. The examiner consciously ignored the flow signal that appeared in the acoustic shadow as RCA flow (a mirror image artifact).

Anomalous Origin

Anomalous origin was found before CPB in 2 patients (1.5%). In Patient 35, the LCA ostium was not found within the left coronary sinus, but was adjacent to the commissure between the non-coronary and left coronary cusps (**Figure 3A**,**B**). In 3D mode, it appeared like a gutter that opened just above the commissures (**Figure 3C**). The anomalous origin had not been recognized in the preoperative CAG. The anomalous LCA ostium was found in the surgical field (**Figure 3D**), but TEE also showed the course of the LCA behind the left coronary sinus, which was not visible to the surgeon. In Patient 24, the RCA ostium was not found in the right coronary sinus (**Figure 3E**); instead, the RCA flow signal was detected in the vicinity of the right coronary sinus wall (**Figure 3F**), which opened at the commissure between the right and left coronary cusps (**Figure 3G**). CAG had indicated a "high ventral takeoff" RCA. Anomalous origin was subsequently confirmed by the surgeon.

Anomalous origin was not found in the remaining patients, except in Patient 9, in whom the latter type of anomaly was present but was not diagnosed by TEE before CPB. Preoperative CAG had indicated a "high ventral takeoff". Upon aortotomy, the RCA orifice was not found, but was recognized by the backflow of cardioplegic solution at the commissure between the right and left coronary sinuses during retrograde cardioplegia. Selective antero-grade perfusion of this vessel was performed using a small cannula.

Low and High Takeoffs (Vertical Deviation)

Although none of the patients in this series had coronary arteries that met the criteria for low takeoff, the coronary ostium occasionally became virtually invisible in the surgical field after the valve prosthesis was placed in the supra-annular position due to a small and rigid coronary sinus. This, in turn, necessitated TEE assessment of coronary blood flow and/or regional wall motion of the left ventricle. In such instances, the TEE findings of pre-CPB assessment were used as reference values.

A high LCA or RCA takeoff was found in 11 patients (8.5%) in total, (RCA n=8; LCA n=6). High takeoff was noted in 4 of 7 patients during concomitant aortic repair (both LCA and RCA in 2 patients; RCA or LCA only in 1 patient each). In Patient 78, in whom high-takeoff RCA was found, the RCA ostium was shown just below the STJ (**Figure 4A**) with a markedly calcified aortic wall above the STJ (**Figure 4B**). Although these findings were confirmed

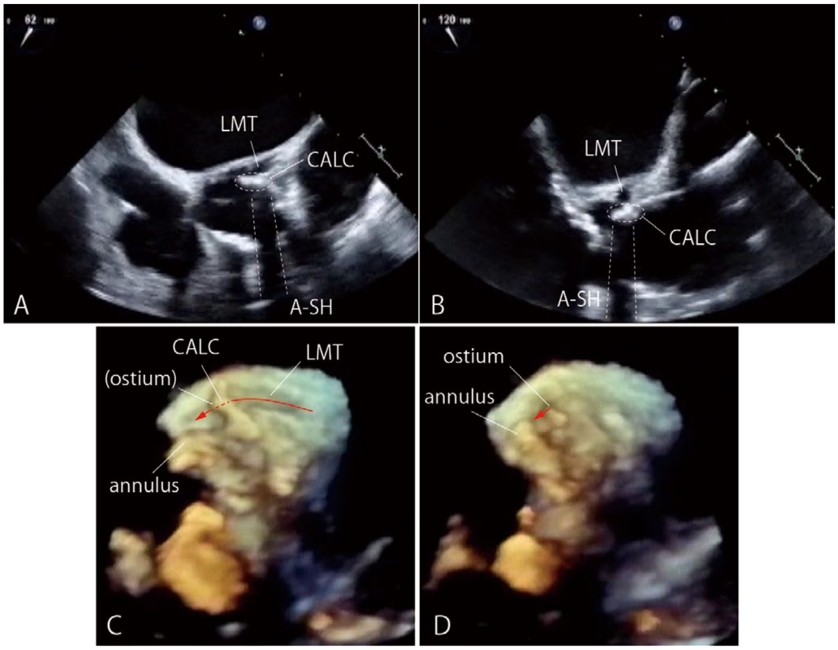

Figure 7. Calcified protrusion (CALC) adjacent to the left coronary artery ostium in Patient 59. (**A**,**B**) Strongly echogenic protrusion adjacent to left main truncus (LMT) associated with acoustic shadow (A-SH) in 2-dimensional images. (**C**,**D**) Protrusion and ostium shown in a 3D image.

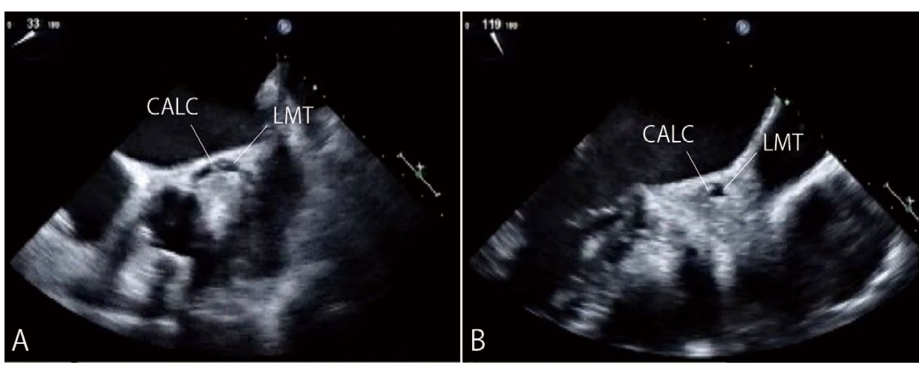

Figure 8. Calcified plaque (CALC) in the left main truncus (LMT) in Patient 64. (**A**) Aortic valve short-axis view. (**B**) Aortic valve long-axis view.

in the surgical field, the surgeon had to incise the aorta close to the RCA to secure the subsequent aortotomy closure. RCA flow was detected immediately after careful closure, but became undetectable after insertion of a hemostatic suture. Epicardial ultrasonography showed an absence of perfusion with a velocity range <10 cm/s (**Figure 4C**). In addition, the inferior wall of the left ventricle was observed to be hypokinetic during TEE, so an additional RCA revascularization was performed on the basis of these findings. The wall motion subsequently improved, and the patient had an uneventful postoperative course.

Coronary Artery Diameter

The diameters of the LCA and RCA measured on TEE images were 4.6±0.8 mm (range 2.5–7.2 mm) and 3.6±0.8 mm (range 1.9–5.7 mm), respectively. The coronary artery diameters measured on TEE images were closely correlated to those measured on CAG images (**Figure 5A**). Mean and maximum LCA diameters in this series are shown in **Figure 5B**,**C**. The diameter of the LCA was >5 mm in 33 patients (25.4%) and >6 mm in 9 patients (6.9%). In Patient 116, the LCA appeared to have 2 separate ostia (**Figure 5D**). However, macroscopic inspection of the surgical field revealed only 1 coronary ostium. When the TEE image was reviewed, the suspected LCX ostium was, in fact, an acoustic shadow generated by nearby calcification.

Short LMT

Short LMT was suspected during TEE assessment in 16 patients, but was misdiagnosed in 1 (Patient 29), as verified by CAG. The actual prevalence of short LMT in the present series was 11.5%. The reason for the misdiagnosis was accelerated flow towards the 6 o'clock direction at 4 mm from the ostium, which was considered to be LAD flow with stenosis just distal to the bifurcation. This flow signal was, in fact, a mirror image in the acoustic shadow generated by the calcified LMT wall (**Figure 6B**). A 90% stenosis was present in the immediately adjacent proximal portion of the LAD, but was located at 20 mm distal from the ostium (**Figure 6C**).

The LMT length was between 5 and 10 mm in 7 patients, confirmed by measurement on CAG. Among patients with an LMT <10 mm, the measurement deviation of LMT length validated by that measured in CAG images was <1 mm in every case. In the remaining patients, the LMT was >10 mm on CAG.

In the most recent case of short LMT (Patient 130), blood flow in the LCA was monitored during selective perfusion. A flow signal was apparently detectable in the LCX but not in the LAD (**Figure 6D**,**E**). An echogenic image was shown in the LCX, indicating that the tip of the cannula reached the LCX. When another larger cannula was used based on these findings, blood flow became detectable in both the LAD and LCX and the image only showed the cannula in the LMT (**Figure 6F**).

Other Specific Findings

In Patient 59, an 81-year-old woman, TEE revealed a strongly echogenic protrusion adjacent to the LCA ostium in the ME AV SAX and LAX views associated with acoustic shadow (**Figure 7A**,**B**). On aortotomy, a calcified protrusion was found just above the LCA ostium as shown in 3D TEE (**Figure 7C**,**D**), which was removed with the ultrasonic surgical aspiration system before selective cardioplegia.

In Patient 64, an 82-year-old woman with concomitant CABG, TEE showed a small plaque in the LMT approximately 1 cm from the ostium (**Figure 8**) that had not been observed during CAG and was not visible in the surgical field. Because the LCA ostium was rather large (4.8 mm), selective cardioplegia was performed carefully so as not to advance the cannula into the LMT too much.

Discussion

Unlike CAG or CT, TEE cannot visualize entire coronary arterial trees, only the ostia and proximal portion.[18] However, TEE appears to be helpful for intraoperative assessment because various events in SAVR usually take place in this region.[2–7] The present study showed that TEE is capable of visualizing: (1) the LCA and RCA in every case; (2) undiagnosed anomalous origin in 2 patients (1.5%); (3) a high-takeoff RCA in 7 patients (5.4%); and (4) short LMT in 15 patients (11.5%), although 1 case of short LMT was misdiagnosed. An LCA ostium >5 mm was found in 33 patients (25.4%). Furthermore, TEE detected RCA occlusion in a case of high takeoff RCA, as well as malperfusion during selective cardioplegia in a case of short LMT.

Location of the Coronary Ostium

According to cadaveric studies, the left and right coronary ostia are located at 8.5–20.0 and 9.9–18.5 mm from the annulus, respectively,[19,20] and no patients in the present study were found to have low takeoff within 5 mm of the annulus. However, visual inspection of the coronary ostium was difficult in patients with supra-annular implantation due to a small annulus, which is common in Japan, particularly in elderly women. On such occasions, TEE assessment of coronary artery perfusion was needed during weaning from CPB. Although it was easy to detect LCA flow, artifacts generated by calcified aorta and prosthetic valves often interfered with the detection of RCA flow. When the flow signal cannot be detected despite meticulous probe manipulation, epicardial ultrasonography with high resolution and a low velocity range (<10 cm/s) was helpful, and the absence of detectable flow is definitely abnormal, as demonstrated by the case of RCA occlusion.

Although cadaveric studies show that the RCA and LCA ostia are located above the STJ in 3.3% and 6.7% of cases, respectively,[19,20] in the present series a high-takeoff around the STJ was found in 6.2% and 4.6% of patients, respectively. There are 2 pitfalls in this variation. One is a risk of RCA occlusion, as experienced in 1 patient, in whom high-takeoff RCA had not been recognized during CAG. The other is an unexpectedly high incidence in patients undergoing concomitant aortic repair (in 4 of 7 patients), because there is a risk of occlusion during dissection around the STJ, proximal anastomosis, or subsequent hemostatic sutures. Thus, it is advised that these findings are verified using TEE and shared with the surgeon, and that coronary perfusion is assessed during weaning from CPB to enable an early decision regarding CABG in the event of unintended coronary malperfusion.[15]

An anomalous origin of the coronary artery is not rare,[19] as found in 3 patients (2.3%) in the present series. Importantly, an anomalous origin of the RCA in 2 patients was not recognized but was considered to be "high ventral takeoff", whereas that of the LCA had not even been suspected during CAG. The common TEE finding was "an absence of a flow signal around the coronary sinus midline" in the ME AV SAX view. In Patient 9, it was impossible to visualize the RCA, and we believe that it was simply undetectable due to marked artifacts. However, it was also hard to visually identify in the severely calcified surrounding tissue, despite an unexceptional RCA image during preoperative CAG. Because the RCA was visualized in the vicinity of the commissure during a careful review of the TEE records, this lesson should be kept in mind. Anomalous origin suggests 2 potential pitfalls for surgeons and TEE examiners. First, it is equal to a low takeoff because the suture line is close to the coronary ostium, despite the CAG finding of "high takeoff". Thus, coronary perfusion needs to be checked during weaning from CPB. Second, the bioprosthesis should be placed in a slightly rotated direction so that the stent post is not located in front of the coronary ostium. This is important to avoid difficult future coronary catheterization. Such foresight will subsequently be of utmost importance because these future SAVR candidates are likely to develop new coronary artery disease after any preceding interventions.

Short LMT and Ostial Diameter

Short LMT is not uncommon, with a reported incidence of 6.5–10% in cadaveric and radiologic studies,[21,22] and 11.5% in the present series. Although cardiologists readily recognize short LMT during CAG, it is usually not described in reports. We ask cardiologists to refer to it in their reports, because the condition is extremely challenging to identify macroscopically in the surgical field. However, a selective perfusion cannula may potentially advance beyond the bifurcation due to the shortness of the LMT, which will lead to inadequate myocardial protection. Although this situation may be suspected if desaturated blood returns from the non-perfused branch,[23] it may not be recognized if the balloon blocks the branch or if there is inadequate collateral circulation between the LAD and LCX. This reminds us of the pitfalls in selective cerebral perfusion, in which a deeply placed cannula in the innominate artery may potentially cause malperfusion of either the left common carotid artery or the left subclavian artery.[24] Although near-infrared spectroscopy is available for detection of cerebral malperfusion, there is no mechanism for monitoring coronary malperfusion. **Figure 6** is the first reported evidence of this event, which can be readily inspected in the ME AV SAX view if the TEE examiner bears it in mind. Although it may not necessarily result in significant myocardial damage in the presence of adequate collateral circulation, it potentially leads to postoperative "cardiac dysfunction of unknown origin", unless LCA perfusion during selective cardioplegia is assessed in real time.

The coronary artery diameter measured in the present study is related to short LMT. In the above-mentioned case, the cannula entered the LMT, which was 4.6mm in diameter. There were as many as 50 patients (38.5%) in whom the LMT was >4.6mm in the present series. In such cases, cardioplegic solution may leak around the cannula, necessitating the insertion of a larger-caliber cannula, which, in turn, prolongs the duration of cardiac arrest. After we had experienced this several times, we started to measure the size of the LCA before aortic cross-clamping to prepare a large-caliber cannula in advance in case it was needed. Although another solution is retrospective cardioplegia, protection of the territory perfused by the RCA may be inadequate. As shown in **Figure 5**, TEE provides fairly accurate measurement of diameter and correctly indicates whether or not the coronary artery is larger than a certain size. The TEE finding allows surgeons to prepare an appropriate strategy for each individual patient.

Limitations of the Study and TEE Assessment

This study has several limitations. First, it is a retrospective observational study of TEE records conducted by a single examiner using a small series. This paper does not aim to provide the results of improved outcomes following the use of TEE assessment. Although a prospective multicenter study is desirable to evaluate the performance and efficacy of TEE assessment, we conducted the present study because there has been no literature reporting such TEE assessment focusing on SAVR. We were concerned that a multicenter study performed without such baseline information may unfairly and inappropriately underestimate the capability of TEE. Thus, the aim of this study was to clarify the ability of TEE to detect various pathologies, as well as tips and pitfalls of TEE assessment.

Several pitfalls mentioned above may be regarded as pointless concerns or merely rare events, because the current outcomes of SAVR are considered favorable.[1] However, in Kochi Medical School Hospital we are already facing the need to prepare for increasingly challenging situations in the coming era by continuous refinement of intraoperative management. For this purpose, we need to expand the extent of suspected events, regardless of their incidence, and completely eliminate "preventable complications". One practical strategy would be to take every possible pitfall into consideration based on meticulous TEE assessment on a routine basis to obtain information not available by preoperative CAG or CT. However, the reality in the operating room is that even experienced cardiologists are not necessarily well acquainted with intraoperative TEE assessment, especially during CPB. Anesthesiologists are often occupied with their primary duty and the time they have available for TEE assessment is limited. Therefore, our attempt to summarize and narrow down the points to be checked and to clarify the pitfalls may also be helpful.

The present study has shown that the pitfalls of TEE assessment were related to artifacts, such as acoustic shadows, side lobes, and mirroring. One may be tempted to ascribe the misdiagnoses in this paper to amateurism, but that would be a grave mistake because the examiner who conducted the investigations has considerable experience. We hope these unfortunate examples and the multitude of lessons learned from our experience will be helpful in preventing misdiagnoses by subsequent, and perhaps less experienced, examiners. The issue of "artifacts" is crucial because an inappropriate strategy based on an incorrect diagnosis may affect outcomes. As more cardiologists become involved in intraoperative assessments going forward as part of a multidisciplinary "heart team", these types of educational issues may be more important than ever.

Conclusions

Despite a number of limitations, TEE is capable of providing many valuable pieces of information that are not available during preoperative assessment, inspection of the surgical field, or by conventional monitors for anesthesiologists. TEE appears to be particularly helpful for recognizing specific problems that would alert surgeons to potential risks, thereby potentially improving the outcomes of SAVR in much more complicated surgical candidates in the future.

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Disclosures

None declared.

IRB Information

This study was approved by Kochi Medical School Ethics Committee (Approval no. 30-55).

References

1. Shimizu H, Okada M, Tangoku A, Doki Y, Endo S, Fukuda H, et al. Thoracic and cardiovascular surgeries in Japan during 2017: Annual report by the Japanese Association for Thoracic Surgery. *Gen Thorac Cardiovasc Surg* 2020; **68:** 414–449.
2. Hazan E, Rioux C, Dequirot A, Mathey J. Postperfusion stenosis of the common left coronary artery. *J Thorac Cardiovasc Surg* 1975; **69:** 703–707.
3. Ehren H, Radegran K. Damage to the right coronary artery as a cause of death after aortic surgery. *Scand J Thorac Cardiovasc Surg* 1991; **25:** 185–187.
4. Sethi GK, Scott SM, Takaro T. Iatrogenic coronary artery stenosis following aortic valve replacement. *J Thorac Cardiovasc Surg* 1979; **77:** 760–767.
5. Winkelmann BR, Ihnken K, Beyersdorf F, Eckel L, Skupin M, März W, et al. Left main coronary artery stenosis after aortic valve replacement: Genetic disposition for accelerated arteriosclerosis

after injury of the intact human coronary artery? *Coron Artery Dis* 1993; **4:** 659–667.
6. Santini F, Pentiricci S, Messina A, Mazzucco A. Coronary ostial enlargement to prevent stenosis after prosthesis aortic valve replacement. *Ann Thorac Surg* 2004; **77:** 1854–1856.
7. Gebereux P, Head SJ, Van Mieghern NM, Kodali S, Kirtane AJ, Xu K, et al. Clinical outcomes after transcatheter aortic valve replacement using Valve Academic Research Consortium definitions: A weighted meta-analysis of 3,519 patients from 16 studies. *Am J Coll Cardiol* 2012; **59:** 2317–2326.
8. Kondo N, Yamamoto M, Kihara K, Wariishi S, Fukutomi T, Nishimori H, et al. Development of a new selective coronary perfusion cannula. *J Artif Organs* 2013; **16:** 411–416.
9. Taams MA, Gussenhoven EJ, Cornel JH, The SH, Roelandt JR, Lancée CT, et al. Detection of left coronary artery stenosis by transoesophageal echocardiography. *Eur Heart J* 1988; **9:** 1162–1166.
10. Zwicky P, Daniel WG, Mügge A, Lichtlen PR. Imaging of coronary arteries by color-coded transesophageal Doppler echocardiography. *Am J Cardiol* 1988; **62:** 639–640.
11. Fernandes F, Alam M, Smith S, Khaja F. The role of transesophageal echocardiography in identifying anomalous coronary arteries. *Circulation* 1993; **88:** 2532–2540.
12. Vicente T, Pinar E, Pérez-Lorente F, López Candel J, Picó F, Pérez de Juan MA, et al. Usefulness of transesophageal echocardiography in the diagnosis of coronary anomalies. *Rev Esp Cardiol* 1996; **49:** 657–662.
13. Kasprzak JD, Kratochwil D, Peruga JZ, Drozdz J, Rafalska K, Religa W, et al. Coronary anomalies diagnosed with transesophageal echocardiography: Complementary clinical value in adults. *Int J Card Imaging* 1998; **14:** 89–95.
14. Koh TW, Ferdinand FD, Jin XY, Gibson DG, Pepper JR. Coronary artery problems during homograft aortic valve replacement: Role of transesophageal echocardiography. *Ann Thorac Surg* 1997; **64:** 533–535.
15. Shapira Y, Vaturi M, Weisenberg DE, Raanani E, Sahar G, Snir E, et al. Impact of intraoperative transesophageal echocardiography in patients undergoing valve replacement. *Ann Thorac Surg* 2004; **78:** 579–583.
16. Watanabe T, Niimi Y, Morita S, Hosoda Y. The detection of coronary ostial lesions by intraoperative transesophageal echocardiography: Report of a case. *Surg Today* 1995; **25:** 646–648.
17. Stevens Q, Ahlgren B, Weitzel N, Reece TB, Puskas F. Intraoperative transesophageal echocardiography to diagnose an anomalous circumflex artery. *J Card Surg* 2013; **28:** 399–401.
18. Samdarshi TE, Nanda NC, Gatewood RP Jr, Ballal RS, Chang LK, Singh HP, et al. Usefulness and limitations of transesophageal echocardiography in the assessment of proximal coronary artery stenosis. *Am J Coll Cardiol* 1992; **19:** 572–580.
19. Joshi SD, Joshi SS, Athavale SA. Origins of the coronary arteries and their significance. *Clinics (Sao Paulo)* 2010; **65:** 79–84.
20. Bhele AV, Ughade HM, Shaikh S, Joge US. A study of course, branches and variations of the coronary arteries in the human cadaveric heart. *Int J Contemp Med Res* 2017; **4:** 1533–1537.
21. Hospanta M, D'Souza AS, Prasanna LC, Bhojaraja VS, Sumalatha S. Anatomical variations in the left coronary artery branches. *Singapore Med J* 2013; **54:** 49–52.
22. Candir N, Ozan H, Kocabiyik N, Kusakligil H. Anatomical risk factors of coronary heart disease. *Balkan Med J* 2010; **27:** 248–252.
23. Armin WE, Martin M, Hans HS. Warning hint of a hidden early left main stem bifurcation during antegrade cardioplegia. *Ann Thorac Surg* 2013; **76:** 1317–1318.
24. Orihashi K, Sueda T, Okada K, Imai K. Malposition of selective cerebral perfusion catheter is not a rare event. *Eur J Cardiothorac Surg* 2005; **27:** 644–648.