特 集 (special edition)

Additional applications of transesophageal echocardiography during cardiac surgery

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Abstract

Additional applications of intraoperative transesophageal echocardiography (TEE) as a "visual ultrasonic stethoscope" was reported. 1) Retained intracardiac air was found in most of the cases with cardiotomy, especially at the right upper pulmonary vein and left ventricle at the weaning from the cardiopulmonary bypass. The air changed its forms (bubbles and pooled form) and locations time after time. 2) Atelectasis and pleural fluid was easily visualized from the esophagus clearly and at real-time, while it is difficult to see from the surgeon and anesthesiologist. 3) Intraaortic balloon pumping: It is important to check the position of the catheter tip and aortic dissection. 4) Swan-Ganz catheter: Important finding was "shuttle movement" of the balloon in the long axis of the pulmonary artery and the "anchoring sign" at wedging. In case of difficult advancement of catheter to the right ventricle or right ventricular outflow tract, TEE provided the problem-oriented solution of this problem, minimizing to abandon the use of catheter. It is important to fully utilize the information of TEE in order to achieve a better intraoperative management.

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Introduction

We have used transesophageal echocardiography (TEE) during cardiac surgery since 1987 and have found several applications of it as a "visual ultrasonic stethoscope" in addition to the popular ones such as evaluation of left ventricular function or valve function, decision-making during aortic surgery and so on. In this paper, we report four additional applications we routinely use intraoperatively.

Subjects and Methods

The subjects are the cardiovascular surgical patients in whom TEE was used intraoperatively as one of the routine monitors since October 1988. Cases between 1988 and 1990 were those at the Albert Einstein College of Medicine (New York) and those thereafter at the Hiroshima University Hospital. We used a 3.5 MHz transesophageal probe (EUB-37LR, Toshiba, Tokyo) and an echocardiographic system (SSA-65A) in the former period or a 5 MHz transesophageal probe (UST-5222V-5, UST-2262-2/3, Aloka, Tokyo) and an echocardiographic system (SSD-860, SSD-870) in the latter period. A transesophageal probe was introduced after induction of anesthesia and intratracheal intubation, and was connected to an echocardiographic system.

Results and Discussion

A. Retained intracardiac air

Complications caused by air include cerebral infarction, temporary or permanent cardiac dysfunction which can be fatal or necessitate additional pump-run. TEE was found to be useful in 1) detecting and locating the air, 2) guiding the air removal, and 3) reconfirmation after removal procedures. We have found "pooled form" of air [1], in addition to the "bubble form" which had been reported by several authors [2, 3]. Both forms of air are found at the time of weaning from cardiopulmonary bypass. The pooled air is depicted as freely movable highly echogenic area, accompanied by side lobes and acoustic shadow or reverberations, shows marked buoyancy and collects at the highest place in each chamber, and pops up by the blood flow or agitation ("popcorn sign") [1] (Figure 1), while bubbles are depicted as highly movable echogenic dots, accompanied by weaker side lobes and show mild buoyancy and collect into the pooled form.

Incidence of pooled air was significantly higher in cases associated with cardiotomy than in those without cardiotomy. At the right upper pulmonary vein (RUPV), left atrium, and left ventricle, the air was found in 93.8%, 56.3%, 68.8% of 16 cases with cardiotomy and in 0%, 0%, 14.3% of 7 cases without cardiotomy, respectively. Figure 2 shows the sites of air retention, comparative with those visualized in the TEE image. The long-axis view of the left heart (the three-chamber view) was useful in detecting and locating the air. Attention should be paid at these sites and right coronary sinus of Valsalva.

Important characteristics of retained air are that, 1) air changes its forms between "bubble form" and "pooled form" and changes locations time after time, 2) its amount can be several milliliters, 3) the air in the RUPV is an ambush, hiding deeply until the pulmonary circulation resumes in spite of rotation of operative suite or hyperinflation of the lung before weaning from bypass. Therefore, a single check-up cannot assure that no air remains, but repeated observations are important. Thus the real-time

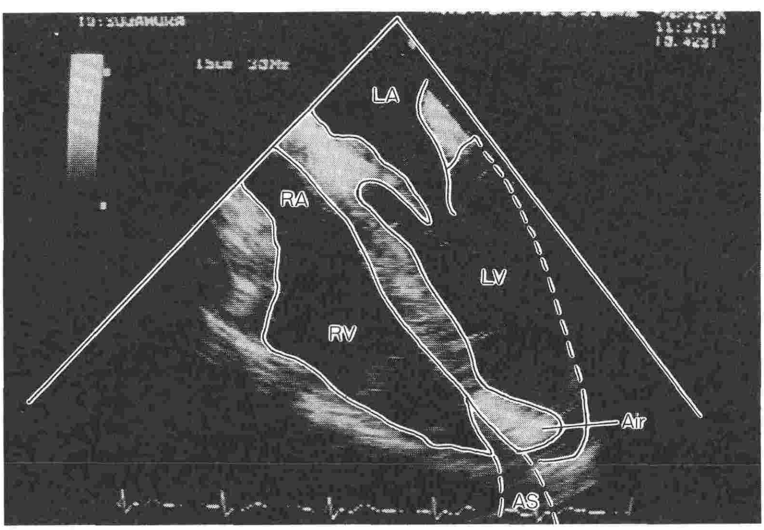

Fig. 1 Pooled air at the left ventricular apex. The air is depicted as a highly echogenic area with side lobes and acoustic shadow. LV: left ventricle, LA: left atrium, RV: right ventricle, RA: right atrium, AS: acoustic shadow.

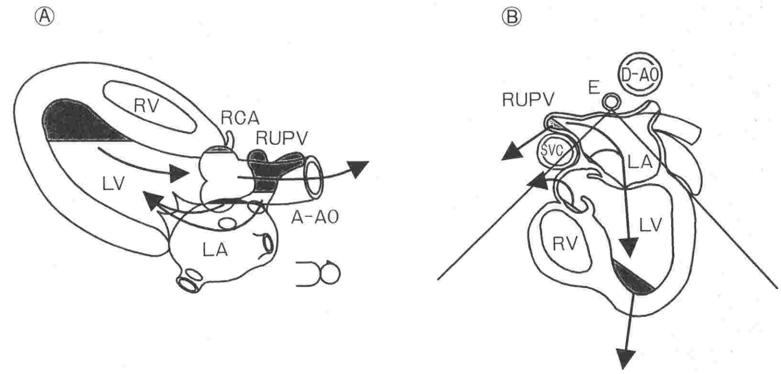

Fig. 2 Sites of air retention (A) in the heart and (B) in the TEE view. A-AO: ascending aorta, RCA: right coronary artery, RUPV: right upper pulmonary vein, E: esophagus, D-AO: descending aorta, SVC: superior vena cava.

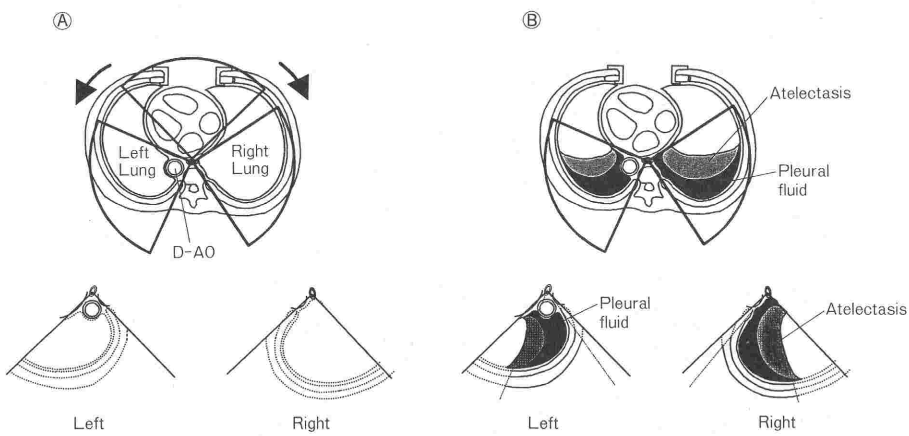

Fig. 3 Visualization of left and right pleural space and corresponding TEE view when pleural fluid and atelectasis are (A) absent or (B) present. D-AO: descending aorta.

monitoring by TEE is useful.

B. Atelectasis and pleural fluid [4, 5]

Atelectasis, a common postoperative complication, was found to occur intraoperatively, especially at harvesting the internal mammary artery graft or during cardiopulmonary bypass when the pericardial space is filled with cold saline or ice slush. When fluid is present in the pleural cavity, it deprives the lung of the space for expansion, as well as it causes hydrostatic pressure which causes atelectatic changes at the dorsal portion of the lung. Inflation of the lung in the reduced space is not effective for reducing the atelectatic portion, while the lung expands towards the surgical field, disturbing the operative procedures. It is not welcomed to lower the PEEP or to reduce the tidal volume when oxygenation of the blood is poor.

These changes are difficult to see from the surgeons and anesthesiologists but are readily visualized from the esophagus. TEE provides real-time, non-invasive, clear visualization of those changes. About 120 degrees of clockwise or counterclockwise rotation of the probe provides the view of right or left pleural cavity, respectively (Figure 3). On the left side, when there was no fluid or atelectasis, the air-filled

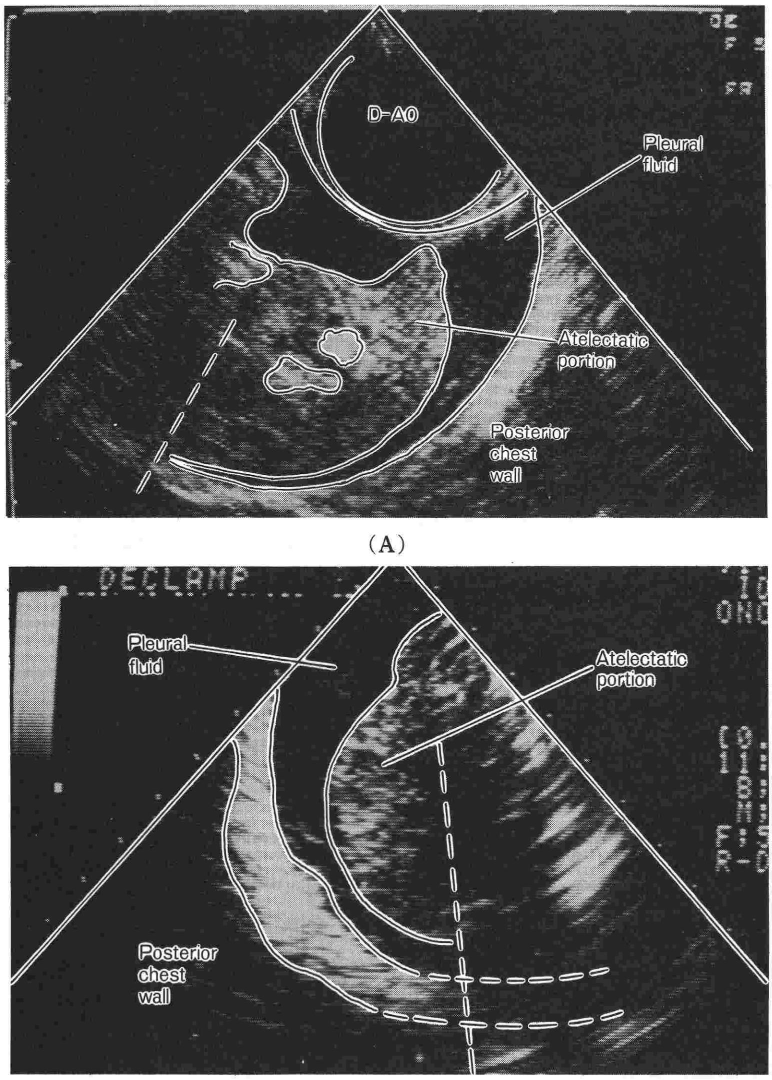

Fig. 4 Atelectasis and pleural fluid (A) on the left side and (B) on the right side. The atelectatic portion is depicted as a solid pattern like the liver, while the pleural fluid is depicted as an echo-free space. Note that the posterior thorax becomes visible through these portions which acts as an acoustic window.

lung caused strong echo adjacent to the descending aorta, masking the image below on the screen. When the fluid or atelectasis was present (Figure 4A), it was depicted as an echo-free area or an hypoechoic solid pattern like the liver, respectively. In addition, the posterior chest wall became visible through the fluid and atelectatic lung as acoustic window. On the right side, the strong echo was seen at the top of the screen when fluid and atelectasis was absent. When atelectasis and pleural fluid are present, an echo-free space and hypoechoic solid pattern appeared (Figure 4B). In the 16 cases of coronary artery bypass surgery with internal mammary artery graft, the incidence of pleural fluid and atelectasis significantly increased from 6.3% and 6.3% in the pre-bypass period to 62.4% and 75.0% in the postbypass period, respectively ($p<0.005$ and $p<0.001$, respectively, chi-square test).

As the fluid was removed, the echo-free area disappeared and the atelectatic lung parenchyma gained a higher echogenicity by hyperinflation of the lung, thus the effect of intervention is confirmed by TEE.

C. Intraaortic balloon pumping (IABP) [4]

TEE was useful for observing the catheter insertion as well as for deciding the indication of starting IABP and evaluating the effect of IABP by monitoring the left ventricular function. In order to achieve the best efficacy, it is important to place the catheter at an appropriate position. The items which can be examined with TEE includes: 1) the presence of catheter in the aorta, not in the inferior vena cava or an extravasation; 2) aortic dissection, especially in the urgent introduction of catheter; 3) position of the catheter tip, which had been examined only with a postoperative chest X-ray; 4) an adequate inflation of the balloon which had been assessed by diastolic augmentation or just by palpation of the aorta; 5) the effect of pumping on the coronary blood flow. Figure 5 shows the four levels of scanning in checking the catheter tip position. At the balloon level, the aortic lumen was filled with echogenic dots at inflation phase and only the catheter image was seen at deflation phase. The catheter was strongly echogenic, accompanied by acoustic shadow and side lobes. At a more proximal level, the catheter image disappeared, then the aortic arch was depicted. The difference of depths of the probe between at the shaft level and the arch level gives an approximate distance between the catheter tip and the base of the left subclavian artery. The normal inflation of the balloon is indicated by the periodic changes at the balloon level, as mentioned before. When an adequate inflation was

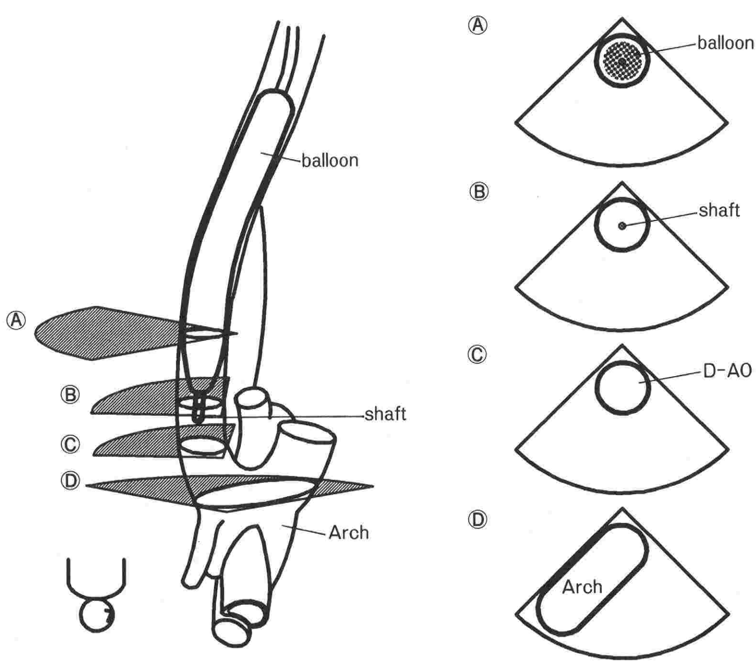

Fig. 5 Levels of scanning an IABP catheter in the descending aorta and corresponding TEE views at each level. A: balloon level, B: shaft level, C: no shaft, D: aortic arch. D-AO: descending aorta.

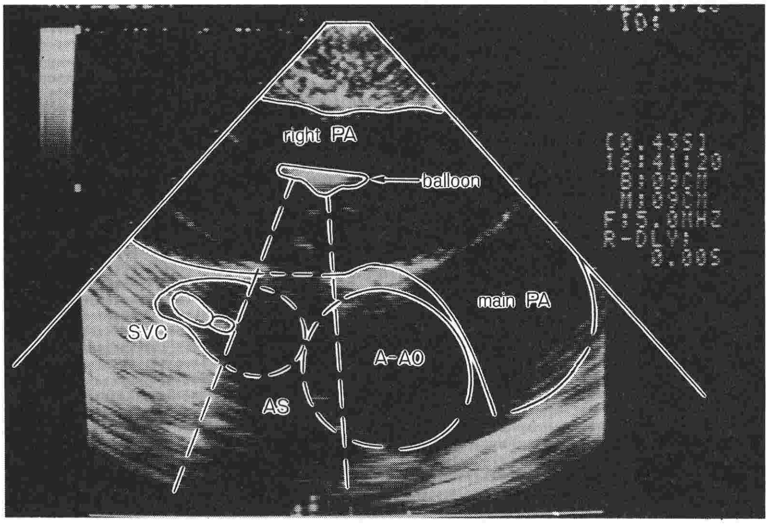

Fig. 6 The balloon in the right pulmonary artery. It is depicted as a strongly echogenic area with acoustic shadow. It shows a shuttle movement in the long-axis direction of the pulmonary artery. PA: pulmonary artery, SVC : superior vena cava.

not seen with absence of diastolic augmentation on the pressure monitor, a kinking of the tube between the catheter and the pumping system was the common cause. TEE also depicts the pathological changes inside the aorta. Intraluminal protrusions were common in the CABG patients [6]. Defoliation of such protrusion can occur at inserting an IABP catheter. Especially careful manipulation of the catheter will be necessary in those patients.

D. Swan-Ganz catheter

The pressure monitor is actually the only guidance in introducing the catheter in the OR, while in the catheter laboratory both fluoroscopy and pressure monitor are available. When it is difficult to advance the catheter to the right ventricle or right ventricular outflow tract, often accompanied by frequent occurrence of arrhythmias, the use of catheter is often abandoned because of an increasing risk by insisting on the insertion in spite of the advantages of the catheter. We have found that TEE in the operating room can be used as a guiding tool like the fluoroscopy in the catheter laboratory.

The catheter was depicted as an echogenic dot with narrow acoustic shadow, while the balloon as an echogenic area with wide acoustic shadow, both accompanied by side lobes [Figure 6]. As the catheter was inserted, the balloon advanced with a shuttle movement in the long-axis direction. The pressure pattern was fully compatible with the location of the balloon image. When the wedge pressure appeared, the balloon disappeared into the distal pulmonary artery with the catheter in the proximal portion immobilized. We have called this finding "anchoring sign".

We experienced several pitfalls in the catheter insertion by means of monitoring by TEE. At an extravasation of the introducer, the image of guidewire was absent in the superior vena cava. When it was difficult to advance the catheter to the right ventricle, the balloon was seen in the inferior vena cava or the catheter was seen immobilized along the right atrial wall. When it was difficult to advance the catheter to the right ventricular outflow tract, the balloon was stuck at the right ventricular apex. The catheter was withdrawn for several centimeters and then advanced again. In one case, the right ventricular outflow tract was too narrow. As the air in the balloon was reduced to half, the catheter easily advanced to the outflow tract. A distal migration of the catheter was found in the postoperative X-ray in 2 of 14 cases. Because an intraoperative unfolding of a loop formation or a long detour of the catheter was considered to be responsible, a re-positioning of the catheter tip was attempted, in which the catheter was withdrawn with the balloon half-inflated until the shuttle movement was seen and then the catheter was advanced until the anchoring occurred. Consequently, the distal migration was not encountered in none of subsequent 20 cases.

E. Summary

The intracardiac or intravascular events cannot be seen directly but have been just guessed using indirect information such as pressure patterns. Thus the intraoperative management has often been ambiguous and anesthesiologists had to consider several possibilities in understanding the pathophysiology or decision-making was done by "a senior doctor", based on his or her experience, which is not always perfect.

TEE has often provided clear-cut visual information to such a gray zone, enabling a more accurate assessment and a more appropriate decision-making, also making the learning curve of young doctors much steeper with far more understandable evidences. The best advantage of TEE is "real-time monitoring", enabling 1) finding and locating the abnormalities, 2) assessing its severity, 3) guiding the intervention for solving the problem, 4) reconfirming the effect of intervention. Repeated procedures of this problem-oriented solution system will greatly improve the efficiency and reliability of intraoperative management.

An esophageal stethoscope had been used before TEE was introduced in our institute. As usefulness of TEE has become obvious, TEE in now considered as "a visual ultrasonic-stethoscope", acting as an eye, ear and more, and now an esophageal stethoscope is not used in cardiac surgery. In this paper we have presented the minor applications, emphasizing the fact that more information is already on the screen to be available than is actually utilized. The maximal benefit of each intervention with the minimal complication can be obtained by accumulating every useful information with the "full" utilization of TEE.

References

1) Orihashi, K., Matsuura, Y., Hamanaka, Y., et al.: Retained intracardiac air in open heart operations examined by transesophageal echocardiography. Ann Thorac Surg **55**:1467-1471, 1993.
2) Oka, Y., Moriwaki, K. M., Hong, Y., et al.: Detection of air emboli in the left heart by M-mode transesophageal echocardiography following cardiopulmonary bypass. Anesthesiology **63**: 109-113, 1985.
3) Topol, E. J., Humphrey, L. S., Borkon, A. M., et al.: Value of intraoperative left ventricular microbubbles detected by transesophageal two-dimensional echocardiography in predicting neurologic outcome after cardiac operations. Am J Cardiol **56**:773-775, 1985.
4) Orihashi, K., Hong, Y. W., Chung, G., et al.: New applications of two-dimensional transesophageal echocardiography in cardiac surgery. J Cardiothorac Vasc Anesth **5**:33-39, 1991.
5) Orihashi, K., Goldiner, P. L.: Pleural fluid and atelectasis (Chapter 15). IN: Transesophageal Echocardiography. Edited by Oka, Y. and Goldiner, P. L. p. 291-302. J. B. Lippincott Company, Philadelphia, 1992.
6) Orihashi, K., Oka, Y.: Intraluminal projection of descending thoracic aorta and intraaortic balloon pump catheter examined by transesophageal echocardiography in patients undergoing coronary artery bypass grafting. Hiroshima J Med Sci **40**: 119-126, 1991.

術中経食道心エコー法 (TEE) の「視診器」としての利用法を報告した．1）心内遺残空気：心腔を開く手術では体外循環離脱時にほぼ全例に認める．貯留型と気泡型が相互に移行しつつ刻々移動する．右上肺静脈，左室心尖部に注意．2）無気肺，胸腔内液貯留：背側に起こり術野からはみにくいが，逆に TEE で明瞭，リアルタイムに観察できる．3）IABP：カテ挿入時にカテ先端位置と大動脈解離の有無を検討する．4）スワン・ガンツカテーテル：カフの shuttle movement, 楔入時これが消失する anchoring sign に注意．カテが進みにくい症例で原因を示唆することもある．TEE の情報を100%活用することにより，より安全，確実な術中管理をめざしたい．