

The Evolution of Intraoperative Transesophageal Echocardiography

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Abstract

In this article, the development of intraoperative transesophageal echocardiography (TEE) is reviewed. It took two decades to develop the present clinical applications of TEE. This modality will continue to serve as a monitor and diagnostic tool to ensure better care of patients in the operating room and the intensive care units.

Key Words: TEE, transesophageal echocardiography, intraoperative TEE.

LORD BYRON STATED THAT “the best of the future is the past.” With this in mind, it may be meaningful and helpful to retrace the historical development of intraoperative transesophageal echocardiography (TEE).

In the early 1960s, during the developmental stages of cardiac surgery and anesthesia, the care of patients in the operating room and during recovery was challenging. There were no mentors to teach us, nor were books available to look up the necessary information. We had to learn how to care for patients from our daily experiences in the operating room and intensive care units. There were no simple and reliable monitoring systems to measure hemodynamic changes.

Although many of these problems were resolved by the latter half of the 1970s, it became apparent that the techniques for measuring cardiac output and various pressures were inadequate to assess rapid changes in ventricular compliance and ventricular performance which occurred during coronary artery bypass surgery. To solve this problem, a great deal of research was required to obtain information on ventricular dimensions and volumes. At about this time, transthoracic echocardiography was recognized by our cardiology colleagues as an effective method for assessing left ventricular dimensions and performance. In 1978, we employed epicardial echocardiography using a commercially available M-Mode transthoracic

probe to evaluate left ventricular function in patients undergoing coronary artery bypass surgery. This technique was useful but quite cumbersome and suffered from a number of inherent problems:

1. The surgeon was forced to interrupt the operation.
2. It was technically difficult to position the probe at the same site and with the same angle relative to the heart for repeated, accurate measurements.
3. There was a risk of infection.

For these reasons, we were constantly searching for a better, simpler approach for determining ventricular dimensions and volumes.

In August 1978, I met Dr. Masayuki Matsumoto, an experienced echocardiographer in the Department of Cardiology at Osaka University, while he was a visiting associate in the laboratory of Dr. Edmond Sonnenblick of the Department of Cardiology at the Albert Einstein College of Medicine. When I met him again in October, he had not yet found a research project and was somewhat frustrated. To comfort him, I invited him to my house for dinner one evening. During an after-dinner conversation on our study of intraoperative epicardial echocardiography, he casually mentioned the work on transesophageal echocardiography by Frazin et al. in 1976 (1), saying that this approach was abandoned because patients found it very difficult to swallow a probe. I suddenly had a flash of inspiration to combine our esophageal stethoscope, which we had been using for anesthetized patients, and an M-Mode echocardiographic probe in the hope that we would be able to determine the ventricular di-

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mensions and volumes. Without delay, I fabricated a handmade transesophageal probe based on an already available probe. The very thin cord was stiffened with a #4 sternal wire and covered with a vinyl esophageal stethoscope catheter. Using this handmade probe, we were able to determine the left ventricular dimensions and calculate the systolic and diastolic volumes, cardiac output and ejection fraction in a 65-year-old woman undergoing mitral valve repair; diastolic and systolic volumes were calculated according to the formula suggested by Teichholz (2). I cannot forget the great joy that we had from the result of this study. This study was published in the *New York State Journal of Medicine* in January 1979 (3). Thereafter, I stiffened this probe even more. Within 6 months, we completed the next study, entitled "Application of Transesophageal Echocardiography to Continuous Intraoperative Monitoring of Left Ventricular Performance." This work was reported at various meetings in the U.S., Europe and Japan (4–10) and published in the *American Journal of Cardiology* in July 1980 (11). Following this study, Dr. Matsumoto left us for the Department of Cardiology in the University of Hamburg, where he continued his M-Mode TEE study. He reported his work on stress echocardiography in 1982 (12).

I continued to work on M-mode transesophageal echocardiography in cardiac surgical patients. From our previous studies, we recognized the limitation of M-mode TEE; therefore, we searched for an engineer to help us design a phased array TEE probe attached to a gastroscope. In the summer of 1980, I had an opportunity to visit the president of a Japanese gastroscope company in New Jersey. I discussed my publications and requested engineering support to design and create the TEE probe. This association ended in great disappointment. In 1982, my friend, Dr. Michio Morio, professor and chairman of the Department of Anesthesiology at Hiroshima University, obtained an M-mode TEE probe attached to a fiberoptic bronchoscopy. Using this probe, we continued our study of left ventricular function and the detection of intracardiac air bubbles (13, 14).

While I was searching for engineering help, Souquet and colleagues in Hamburg, Germany, introduced the electronic phased-array transducer in 1982, which represented a definitive breakthrough for the transesophageal approach (15). The initial application of this probe was described at the University of San Francisco for intraoperative monitoring of regional myocar-

dial function in high-risk, non-cardiac surgical patients and the recognition of intracardiac air during neurosurgical procedures (16).

During the period 1983–1986, our research work on TEE failed to show much progress because of the lack of engineering help. In the winter of 1986, I met the chairman and chief operating officer of Toshiba America Co. in New York City. He came to the anteroom where I sat, carrying reprints of my publications and asked me what he could do to help me. I explained my work on TEE and told him that I needed engineering help to develop a clinically useful TEE probe. I remember I had a hard time convincing him to support my undertaking. Although he was a dynamo in the business world, he was not well versed in medicine. After a long discussion of the project, I showed him my article in the February 1980 issue of *Anesthesiology News* (5) entitled "New Device Will Facilitate Intraoperative Cardiac Monitoring." He suddenly showed interest in my work and promised that he would contact the responsible individuals in the medical division of Toshiba, Tokyo. In April 1987 (during the best time for cherry blossoms in Tokyo), I met two senior engineers in the medical division of Toshiba Company. That August, we signed an official agreement regarding cooperative development of Toshiba Ultrasound Products for TEE in the operating room and intensive care unit.

We continued to have a meaningful association with Toshiba Company, which led to the most productive years of our TEE research and research fellowship program. Late in the 1980s, color flow mapping combined with higher resolution imaging was introduced to TEE and used by a number of investigators. This led to an explosive and widespread increase in the application of TEE in anesthesiology, cardiac surgery, and cardiology. In 1989, mechanically driven high-frequency transducers with an annular array providing both high resolution and the capability for continuous wave Doppler interrogations were developed (17, 18). Omoto et al. introduced biplane TEE in 1989 (19) to overcome the lack of versatility associated with imaging structures only in the transverse plane. Biplane TEE employed two phased array transducers (one imaging in the transverse and one in the longitudinal plane) that were mounted at the tip of a gastroscope. Each transducer had 32 elements and operated at 5 Mhz. The distance between the centers of the two transducers was 1 cm. As a conse-

quence, minimal repositioning of one transducer was required to visualize exactly the same cardiac segment. To overcome the problem of repositioning, a phase array matrix was developed which allowed orthogonal biplane scanning from one transducer which was kept at constant position. At that time our new chairman, Dr. Paul Goldiner, strongly supported this corporate alliance as well as our TEE research.

By 1990, many companies began to produce commercially available 2D color Doppler biplane TEE probes with improvements in echo systems. In 1992, Pandian et al. reported 3D-4D TEE in humans using a computed tomographic imaging probe (20); however, this modality is not yet commonly used.

It took two decades to reach the present status of intraoperative TEE. There is no doubt that the application of this technology in cardiac anesthesia was a turning point in the care of patients in the operating room and intensive care unit. I believe that this technology will continue to serve as a monitor and diagnostic tool to ensure the superior care of patients in cardiac surgery. Its applications will be extended to other patients in critical conditions. I am extremely pleased to have witnessed the numerous innovative and challenging developments of this modality by so many creative investigators.

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