Effect of lateral body position on transesophageal echocardiography images and the association with patient characteristics: A prospective observational study

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ABSTRACT

Background: Changes in heart position are occasionally observed on the transesophageal echocardiography (TEE) image screen after changing the body position from supine to lateral, although the magnitude of change in cardiac position varies individually. We hypothesized that this variation is associated with certain patient characteristics and evaluated how lateral positioning affects visualization of the heart on TEE and whether the magnitude of change in the heart position correlates with patient characteristics.

Methods: Fifty-three lung resection patients were enrolled. Two angle and two length parameters (ΔθTV, ΔθAP, ΔLT, and ΔLP) were defined to describe location change of the lateral tricuspid annulus and right ventricular apex on the TEE image between supine and lateral position. The correlation coefficients were calculated between these four parameters and patient characteristics, including age, body mass index (BMI), epicardial fat thickness, and pulmonary function variables.

Results: The ΔθTV correlated positively and inversely with BMI in both right and left lateral patients (right: r = 0.6365, P = 0.0034; left: r = −0.6616, P < 0.0001, respectively). In left lateral patients, the ΔθTV correlated inversely with epicardial fat thickness (r = −0.4879, P = 0.0182), and the ΔLP correlated positively with the forced vital capacity percent predicted (r = 0.5736, P = 0.0082).

Conclusions: Lateral body positioning affects cardiac visualization on TEE, and the BMI, epicardial fat thickness, and pulmonary function moderate this effect.

Key words: Body mass index; Body position; Heart position; Pulmonary function; Transesophageal echocardiography

INTRODUCTION

The American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists recommend the use of transesophageal echocardiography (TEE) in patients with cardiovascular pathology undergoing noncardiac surgery.1(1) When intraoperative TEE monitoring is performed during surgeries requiring lateral body positioning, a baseline TEE examination should be performed with the patient supine before being placed in the lateral position. Occasionally, changes in the cardiac image on TEE are observed after lateral body positioning; however, the magnitude of these changes varies individually. Some laterally positioned patients require additional adjustment of the TEE probe, such as flexion or turning, to acquire TEE images equivalent to those in the supine position, but other patients do not require any additional probe adjustment. This led us to speculate that although body position affects visualization of the heart on...
TEE, the effect varies among individuals. The effects of prone positioning on the heart location have been assessed quantitatively using computed tomography, which suggests that the heart moves anterior (closer to the anterior chest wall) during prone positioning; however, the effects of lateral body position on the heart position in TEE have not been assessed. Therefore, we evaluated the effects of lateral body positioning on visualization of the heart on TEE images and analyzed the correlation between the magnitude of change in the heart position and patient characteristics.

**METHODS**

**Study population**
The study protocol was approved by our Institutional Ethics Committee, and informed consent was obtained from all participants. This prospective observational study included patients undergoing elective open or thoracoscopic lung resection for lung cancer. Patients with a history of lung and heart surgery, pleural effusion and other pleural diseases, pericardial effusion, mediastinal masses, and contraindications to TEE were excluded.

**Transesophageal echocardiography image acquisition**
After general anesthesia was induced and the airway secured by tracheal intubation, a multiplane TEE probe (X7-2t, Philips Medical Systems, Bothell, WA, USA) was inserted into the esophagus and connected to the echocardiography system (iE33, Phillips Medical Systems, Bothell, WA, USA) for image acquisition. The TEE probe used in our study protocol was adjusted only by advancement and withdrawal, and manipulated for the marker of the depth to locate at just center in both body positions. The TEE probe was not turned to the right or left, the probe tip was not flexed, and the imaging plane was not rotated but remained fixed at 0°. These limitations maintained the orientation of the TEE scanning plane in the two body positions and enabled us to qualitatively assess the change in the heart position. The lateral tricuspid annulus and the right ventricular (RV) apex were designated as reference points to assess change in heart position and were observed using the following protocol. We first advanced the TEE probe until the lateral tricuspid annulus, and the RV apex were simultaneously visible in one image plane at 0°. These two reference points could not be visualized in one image plane in the supine position, then the patient was excluded from the study. We then marked the probe depth and acquired an image at the end of diastole. After placing the patient in a 90° lateral position, another image was acquired using the same protocol with the TEE probe at the same depth. During image acquisition both in supine and lateral position, mechanical ventilation was temporarily discontinued, and the surgical table was kept level. The Valsalva maneuver was not performed to modify image quality. All images were acquired by a single anesthesiologist.

**Echoangiographic measurements**
Echocardiographic measurements on the acquired TEE images were obtained postoperatively by an anesthesiologist who was not involved in image acquisition and blinded to the patients’ characteristics. At least 1 week after the initial measurement, the echocardiographic parameters on the stored images were measured a 2nd time by the same anesthesiologist and by a different observer to assess the intra- and inter-observer variability, respectively. Initial and secondary values were compared by calculating the correlation coefficient to determine the reproducibility of the measurements. To describe the lateral tricuspid annulus and RV apex locations, three lines were drawn on the TEE image screen, and two angles and two lengths were measured as follows [Figure 1]: TV: The line connecting the lateral tricuspid annulus and TEE probe transducer; AP: The line connecting the RV apex and TEE probe transducer; BS: The line bisecting the TEE screen. The θ_{TV} was the angle between the TV and BS, and the θ_{AP} was the angle between the AP and BS. The lengths of TV and AP were defined as L_{TV} and L_{AP} respectively. In this image, the θ_{TV} and θ_{AP} values were −26° and +17°, respectively.
apex and TEE probe transducer; BS: The line bisecting the TEE screen; θ
TV: The angle between TV and BS; θ
AP: The angle between AP and BS; L
TV: The length of TV; and L
AP: The length of AP. The θ
TV and θ
AP values were positive when the TV and AP were located right of the BS and negative when they were left of the BS [Figure 1]. The differences in the θ
TV, θ
AP, L
TV, and L
AP according to the change in body position from supine to lateral were calculated and defined as the Δθ
TV, Δθ
AP, ΔL
TV, and ΔL
AP respectively [Figure 2].

Analysis of patient characteristics

Patient characteristics were collected from the medical records, including the age, body mass index (BMI), forced vital capacity as percent predicted (FVC% predicted), and the percentage predicted of forced expiratory volume in 1 s (FEV1.0% predicted). In addition, the epicardial fat thickness, which appeared as a hypoechoic space anterior to the RV free wall on TEE, was also analyzed. The epicardial fat thickness and echocardiographic parameters of θ
TV, θ
AP, L
TV, and L
AP were measured simultaneously on a single TEE image. The epicardial fat thickness was measured when the hypoechoic space was clearly confirmed. The intra- and inter-observer variability in the epicardial fat thickness measurement was assessed as described for the echocardiographic parameters.

Statistical analysis

Data were expressed as the mean ± standard deviation or the mean with a range for continuous variables, and as numbers for categorical variables. Normal distribution was confirmed in each variable using the Kolmogorov–Smirnov test. Correlations between the Δθ
TV, Δθ
AP, ΔL
TV, and ΔL
AP and patient characteristics were analyzed using Pearson’s or Spearman’s correlation coefficient (r). A linear regression analysis was performed to determine the relationship between the Δθ
TV and Δθ
AP. A P < 0.05 was considered statistically significant. All calculations were performed using GraphPad Prism 6.0 (GraphPad Software, La Jolla, CA, USA).

RESULTS

A total 61 patients were enrolled in this study. Eight patients were excluded due to suboptimal images; therefore, the TEE images of 53 patients aged 46–80 years were analyzed. Lung resection was performed in the right lateral position in 20 patients and the left lateral position in 33 patients. The patient characteristics are shown in Table 1. The epicardial fat thickness could only be measured in 48 patients and correlated positively with the BMI (r = 0.4663, P = 0.0024).

The point of the posterior wall of the left atrium just below the top of the sector was unchanged in the two body positions in any of the patients, evaluating the spatial relationship between the point and surrounding tissue including inter-atrial septum, right atrium, and

| Parameters | Right lateral | Left lateral |
|------------|--------------|-------------|
| Number of patients | 20 | 33 |
| Age, years | 68.1±5.7 | 67.4±8.8 |
| Sex, male | 15 | 24 |
| BMI, kg/m² | 23.3±3.3 | 23.6±2.8 |
| FVC% predicted, % | 86.4±19.7 | 94.1±16.7 |
| FEV1.0% predicted, % | 76.2±17.0 | 70.4±19.0 |
| Epicardial fat thickness, mm | 2.4 (1.2-4.4) | 2.8 (0.9-11.9) |
| θ
TV, ° | Supine | −18.0±15.1 | −23.4±17.0 |
| | Lateral | −29.5±11.7 | −3.5±12.7 |
| Δθ
TV, ° | Supine | −14.2±15.8 | 20.0±14.5 |
| | Lateral | −11.1±13.0 | 13.2±14.4 |
| L
TV, cm | Supine | 6.5±1.4 | 6.4±1.0 |
| | Lateral | 6.8±1.3 | 6.9±1.2 |
| ΔL
AP, cm | Supine | 0.5±0.9 | 0.5±0.8 |
| | Lateral | 8.2±1.6 | 8.4±1.5 |

BMI: Body mass index, FVC% predicted: Forced vital capacity as percentage predicted, FEV1.0% predicted: Percentage of forced expiratory volume in 1 s
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atrio-ventricular valves. Figure 3 shows the $\theta_{TV}$, $\theta_{AP}$, $L_{TV}$, and $L_{AP}$ in the supine and lateral positions. The changes in each parameter varied individually between the patients. The $\theta_{TV}$ and $\theta_{AP}$ tended to decrease in patients positioned right lateral and increased in patients positioned left lateral [Figure 3]. Since either the lateral tricuspid annulus or the RV apex was not visible in the lateral position, the $\Delta \theta_{TV}$ and $\Delta L_{TV}$ in one right lateral positioned patient and the $\Delta \theta_{AP}$ and $\Delta L_{AP}$ in 18 patients (13 in left and 5 in right lateral positioned) could not be calculated. In the remaining 34 patients, the $\Delta \theta_{AP}$ correlated positively with the $\Delta \theta_{TV}$ in both right and left lateral patients (right lateral: $r = 0.7265$, $P = 0.0033$; left lateral: $r = 0.8456$, $P < 0.0001$), [Figure 4]. The linear regression equations of $\Delta \theta_{AP}$ with $\Delta \theta_{TV}$ in the right and left lateral positioned patients were: Before: $y = 1.069x - 5.988$ After: $y = 0.6487x - 0.6303$, ($R^2 = 0.5278$, $P = 0.0033$) and Before: $y = 0.6487x - 0.6303$ After: $y = 1.069x - 5.988$, ($R^2 = 0.7150$, $P < 0.0001$), respectively. The $\Delta \theta_{TV}$ correlated positively and inversely with the BMI in right and left lateral positioned patients ($r = 0.6365$, $P = 0.0034$; and $r = -0.6616$, $P < 0.0001$, respectively), [Figure 5a and b]. The $\Delta \theta_{TV}$ was generally negative in right lateral positioned patients and positive in those positioned left lateral. To analyze the correlation between the BMI and $\Delta \theta_{TV}$ in all 53 patients, the opposite values of $\Delta \theta_{TV}$ ($-\Delta \theta_{TV}$) were calculated in the right lateral positioned patients. The $-\Delta \theta_{TV}$ in right lateral positioned patients and $\Delta \theta_{TV}$ in left lateral positioned patients were summed, and the total was defined as the $\Delta \theta_{TVall}$. The $\Delta \theta_{TVall}$ correlated inversely with the BMI ($r = -0.6310$, $P < 0.0001$), [Figure 5c]. The $\Delta \theta_{AP}$ did not correlate with the BMI in either patient group (right lateral: $r = 0.1461$, $P = 0.6035$; left lateral: $r = -0.3056$, $P = 0.1901$). In the left lateral patients, substitution of the 18 missing $\Delta \theta_{AP}$ values by regression estimation using the calculated regression equations indicated a negative correlation between $\Delta \theta_{AP}$ and BMI ($r = -0.5891$, $P = 0.0003$), and the $\Delta \theta_{TV}$ correlated inversely with epicardial fat thickness ($r = -0.4879$, $P = 0.0182$). Although the $\Delta L_{TV}$ in the right lateral patients did not ($r = -0.3499$, $P = 0.2011$), [Figure 5d], the $\Delta L_{AP}$ in the left lateral patients correlated positively with FVC% predicted ($r = 0.5736$, $P = 0.0082$), [Figure 5e]. The patient age and FEV1.0% predicted were not correlated with the $\Delta \theta_{TV}$, $\Delta \theta_{AP}$, $\Delta L_{TV}$, and $\Delta L_{AP}$. All interclass correlation coefficients were $> 0.9$ with $P < 0.0001$ for both intra- and inter-observer analysis, showing good reproducibility of the measurements.

Figure 3: Changes in $\theta_{TV}$, $\theta_{AP}$, $L_{TV}$, and $L_{AP}$ between the supine and lateral positions. The right and left columns of the graph represent the left and right laterally positioned patients, respectively

Figure 4: Correlation between the $\Delta \theta_{TV}$ and $\Delta \theta_{AP}$ in right (a) and left (b) laterally positioned patients. The regression lines are also shown in both panels. The definitions of $\Delta \theta_{TV}$ and $\Delta \theta_{AP}$ are shown in Figure 2. $R$: Pearson’s correlation coefficient
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DISCUSSION

We observed that the $\Delta \theta_{TVall}$ correlated inversely with BMI. The spatial relationship between the TEE probe and posterior wall of the left atrium did not change before and after lateral positioning; therefore, the $\Delta \theta_{TVall}$ represents the rotation angle of the lateral tricuspid annulus on the TEE probe axis as observed on the TEE screen, along with the change in body position. Thus, lean patients have greater movement of the lateral tricuspid annulus toward the lower lateral side of the body during lateral positioning than that observed in obese patients.

The movement of the lateral tricuspid annulus on TEE images may reflect characteristics of the mediastinum. The mediastinum is mobile because it is supported by loose connective tissue and surrounded by elastic lungs. This mobility causes the mediastinum to move toward the lower side after lateral positioning, contributing to the altered visibility of the heart on TEE images.

The correlation between $\Delta \theta_{TVall}$ and BMI may be caused by the relationship between body weight, pleural pressure, and epicardial fat. An animal study by Bloomfield et al. showed a significant increase in the pleural pressure following an increase in the intra-abdominal pressure caused by intraperitoneal balloon inflation. In a study by Owens et al., the esophageal pressure, which approximates pleural pressure, was higher in obese patients than in lean patients and correlated positively with BMI ($R^2 = 0.19$, $P < 0.01$). They suspected that the increased chest wall mass and intra-abdominal pressure, also higher in the obese subjects, may result in a higher esophageal pressure or pleural pressure in overweight or obese subjects. We think that the relatively higher pleural pressure in patients with a higher BMI decreases mediastinum and lung mobility, resulting in the inverse correlation between BMI and $\Delta \theta_{TVall}$ presently observed. We also found a positive correlation between the epicardial fat thickness and BMI. This finding is consistent with findings reported by Sacks and Fain in which the epicardial fat thickness was greater in

![Figure 5: Correlation between the $\Delta \theta_{TVall}$ and body mass index (BMI) (black circles) and between the $\Delta L_{AP}$ and forced vital capacity as percent predicted (FVC%) (black quadrangles).](image-url)
higher BMI patients.\textsuperscript{[7]} Moreover, the Δθ\textsubscript{TV} in left lateral patients correlated negatively with an epicardial fat thickness in our study. Thus, the greater epicardial fat deposition may restrict cardiac movement as the body position changes in higher BMI patients. Based on these two mechanisms, the Δθ\textsubscript{TVall} may correlate negatively with BMI.

The Δθ\textsubscript{AP} did not correlate with BMI ($r = 0.1461$ and $-0.3056$ with $P = 0.6035$ and 0.1901 in right and left lateral positions, respectively) despite the significant positive correlation between Δθ\textsubscript{TV} and Δθ\textsubscript{AP}. The Δθ\textsubscript{AP} was determined based on only 34 of 53 patients because the RV apex could not be visualized in the lateral position due to the limited scan angle of TEE using our protocol. Substitution of the 18 missing Δθ\textsubscript{AP} values by regression estimation using the linear regression equations generated a negative correlation between the Δθ\textsubscript{AP} and BMI in the left lateral position; thus, the smaller sample size in the Δθ\textsubscript{AP} analysis compared to the Δθ\textsubscript{TV} analysis may have caused an insignificant correlation between the Δθ\textsubscript{AP} and BMI. The image quality of trans-thoracic echocardiography (TTE) is usually improved in left lateral position, which can be understood by the heart position close to the left chest wall. The result of our study in left lateral position would support this phenomenon, because the movement of the lateral tricuspid annulus and RV apex in anterior side of the heart toward the lower left lateral side would imply that the heart approached to the arc-shaped left anterior lateral chest wall. Further, the inverse correlation of Δθ\textsubscript{TV} and Δθ\textsubscript{AP} with BMI would indicate the restriction of the heart movement in patients with higher BMI, which may cause the poor resolution during the TTE examination in obese patients.

The ΔL\textsubscript{AP} and FVC\% predicted were significantly positively correlated in left lateral patients. Our simple probe manipulations, which did not employ flexion or turning of the TEE probe, generated a modified midesophageal four-chamber view at 0°, which foreshortens the apex.\textsuperscript{[6]} Therefore, the increase in ΔL\textsubscript{AP} with the position change means that left lateral positioning improves foreshortening in the TEE image as the mediastinum moves toward the lower lateral side of the body. Jones and Nzekwu found an inverse correlation between FVC\% predicted and BMI.\textsuperscript{[8]} The positive correlation between ΔL\textsubscript{AP} and FVC\% predicted in our study may reflect the effect of BMI on ΔL\textsubscript{AP}; however, FVC\% predicted and BMI did not correlate significantly in our study population ($r = -0.2228$, $P = 0.1088$). Although this may result from the smaller sample size and lower BMI in our study compared to those in the study by Jones and Nzekwu (18.7–30.9 in 53 patients; and 20–40 kg/m\textsuperscript{2} in 373 patients, respectively), the reason underlying the correlation between ΔL\textsubscript{AP} and FVC\% predicted in our study remains unclear.

Chino and Marks analyzed the effects of the prone position on heart location using computed tomography.\textsuperscript{[9]} Although the magnitude of anterior cardiac displacement varied individually, this was not related to age, which alters the connective tissue elasticity.\textsuperscript{[7]} These previous results are consistent with the insignificant correlation between age and the four parameters measured presently.

The present study has some limitations. First, TEE provides a limited sector-shaped image with a 90° central angle. The limited-angle image obtained using our protocol, in which the TEE probe was not turned or flexed during evaluation of the relative changes in heart position, caused us to miss the Δθ\textsubscript{AP} and ΔL\textsubscript{AP} values in 18 patients. As a result, our data were generated from a limited patient population. Second, our protocol may have led to inadequate data acquisition in patients expected to have a great magnitude of change in cardiac position on the TEE image. Finally, we measured the cardiac positional change using a two-dimensional imaging plane. Three-dimensional images with a wider sector angle may depict intrathoracic cardiac position change more precisely; however, the three-dimensional scanning angle has limited ability to obtain an entire image of the heart in both body positions. In addition, changes in the heart position within the mediastinum cannot be evaluated quantitatively with the software currently available for three-dimensional data analysis in the iE33 echocardiography system (Q Lab, Phillips Medical Systems, Bothell, WA, USA).

**CONCLUSION**

Lateral body positioning alters visualization of the heart in TEE images, and individual variations in these changes may be related to patient characteristics, such as BMI and pulmonary functional parameters, such as FVC\% predicted. Examiners should perform additional probe manipulation during TEE to ensure a good depiction of the heart in select laterally positioned patients, especially those with a lower BMI or higher FVC\% predicted.
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