Measurement of Pleural Pressure with Esophageal Balloon in Anesthetized Humans


Simultaneous measurement of tracheal and esophageal pressures during unoccluded inspiratory efforts (occlusion test) was used to assess the validity of the esophageal balloon technique in anesthetized supine subjects. Ten ASA I patients undergoing general anesthesia (halothane 1 MAC, nitrous oxide 70%, and oxygen) for minor surgery were studied. Esophageal pressure (Pes) was measured using a 5-cm-long balloon and was plotted against tracheal pressure (Pt). Occlusion tests were performed at end expiration with the balloon top positioned 5, 10, 15, and 20 cm above the cardia. The results show that with the balloon positioned at the classical level of 10 cm above the cardia, the difference between ΔPes and ΔPt did not exceed 8% in seven of 10 subjects. In the remaining three, however, the difference between ΔPes and ΔPt ranged between +20% and -40%. By repositioning the balloon to 5 or 15 cm above the cardia, a locus was found in all subjects where the difference is less than 10%. We conclude that the esophageal balloon technique can be used in anesthetized supine subjects to give reliable measurements of changes in pleural pressure, provided that it is validated with the occlusion test. (Key words: Lung; pleural pressure. Measurement techniques: occlusion pressure; pleural pressure. Position: supine.)

THE ESOPHAGEAL BALLOON TECHNIQUE is used widely in the measurement of lung mechanics.1 In the supine position, however, the validity of the pressure measurements from the balloon has been questioned.2,3 Static inspiratory and expiratory efforts with an open glottis and a closed external airway (Mueller and Val-sava maneuvers) have been proposed to validate the technique.4,4 Equal changes in esophageal (ΔPes) and

ΔPt pressures during these maneuvers indicate that changes in esophageal pressures provide a valid estimate of changes in pleural surface pressure. This approach requires cooperation from the subject and cannot be applied in anesthetized subjects. An alternative is to compare ΔPes and ΔPt during spontaneous respiratory efforts made against a closed external airway. This "occlusion test" has been used by Milner et al.5 and Beardsmore et al.6 in neonates. Asher et al.7 have used it to verify the accuracy of the esophageal water-filled catheter technique in neonates. Baydur et al.8 have used the "occlusion test" in awake adults in different body positions (sitting, lateral, and supine). They found that in some supine subjects, repositioning of the esophageal balloon was necessary to obtain satisfactory ΔPes/ΔPt ratios during unoccluded inspiratory efforts.

During anesthesia, the esophageal balloon technique has been used by many authors,9-13 who have followed the conventional method of positioning the balloon (balloon top 10 cm above the cardia), but the validity of the technique in anesthetized supine subjects has not been assessed previously, except for Westbrook et al.11 and Rehder et al.10 In anesthetized, paralyzed subjects, they manually compressed the chest for detection of recording artifacts. They stated that ΔPes and ΔPt were "rather similar," but did not provide quantitative data.

The purpose of this study was to test the accuracy of the conventional balloon technique in estimating pleural pressure in subjects anesthetized while in the supine position, using the occlusion test.

Materials and Methods

Ten subjects undergoing general anesthesia for a variety of surgical procedures were studied. Their average age (±SD) was 33.7 ± 12.7 yr and body surface area 1.7 ± 0.15 m². All subjects were ASA 1. The study was approved by the hospital Ethics Committee, and informed consent was obtained from all individuals.

Esophageal pressure (Pes) was recorded using a 5-cm-long balloon with a circumference of 3.2 cm. The balloon was sealed over one end of a polyethylene catheter (id 1.4 mm; length 94 cm) with several side holes within
the balloon. The other end of the catheter was connected to a Validyne MP 45 differential pressure transducer. The volume–pressure curve of the balloon was flat within a range of volume between 0.2 and 5 ml. Using a similar catheter (but without balloon) and another Validyne MP 45 transducer, tracheal pressure (Pt) was measured at the proximal end of the endotracheal tube. The Pes and Pt systems were tested with a sine-wave pressure generator and found to have a flat frequency response up to 20 Hz. Transpulmonary pressure (Ptp) was obtained by electronic subtraction of Pes from the Pt signal. Flow (V) was measured with a Fleisch No. 2 pneumotachograph, connected to a Validyne MP 45 (±2 cm H₂O) differential pressure transducer, and volume (V) was obtained by integrating the flow signal (HP 8815A integrator). All signals were amplified (Hp 8805A amplifiers) and recorded on a Gould Brush 2600 6-channel recorder and on tape (HP 3966A tape recorder). Tracheal versus esophageal pressure was displayed on a Tektronix storage-oscilloscope (Tektronix® LC-5) and photographs were taken using a Tektronix polaroid camera.

**PROCEDURE**

Anesthesia was induced in all subjects with halothane in a mixture of 70% nitrous oxide and oxygen, and tracheal intubation was performed without the use of a muscle relaxant. Anesthesia was maintained with halothane (~1 MAC) and nitrous oxide and oxygen. The subjects breathed spontaneously throughout the experiment. The esophageal balloon was emptied of air and introduced transorally under direct vision into the esophagus. The balloon was filled with 0.5 ml air and passed into the stomach. The balloon then was withdrawn until a negative pressure deflection was recorded during inspiration. Subsequently, the balloon was withdrawn into the esophagus and positioned with the top 5 cm from the cardia. The balloon gas volume was checked at frequent intervals.

The "occlusion test" was performed by occluding the external airway at end expiration (functional residual capacity—FRC) and simultaneously recording the esophageal and tracheal pressure changes during the following two or three occluded inspiratory efforts. The records of ΔPes versus ΔPt also were displayed on the storage oscilloscope and photographed, allowing on line measurement of the slope. The balloon then was withdrawn to 10, 15, and 20 cm from the cardia, and the occlusion tests were repeated.

Movements of the heart cause changes in Pes. The magnitude of this cardiac artifact was measured at each balloon position, and analysis of variance was applied to these data.

![Fig. 1. Representative tracing of flow (V), volume (V), tracheal (Pt), esophageal (Pes), and transpulmonary (Ptp) pressures during an occlusion test. Dotted lines indicate variations of Ptp resulting from the cardiac artifact. Balloon level: 10 cm above cardia; Subject 2.](http://anesthesiology.pubs.asahq.org/pdfaccess.ashx?url=/data/journals/jasa/931430/)

**Results**

Figure 1 shows a tracing of an occlusion test. It can be seen that during the occluded inspiratory effort, apart from the cardiac artifact, Ptp remained nearly constant, indicating that the changes in esophageal pressure were close to the corresponding changes in Pt, i.e., in this case the ΔPes/ΔPt ratio was near to unity. A similar result also is shown in figure 2, which is a tracing of ΔPes versus ΔPt obtained on the oscilloscope during an occlusion test. It can be seen that the relationship is linear with the slope close to unity, the deviations from the line of identity representing cardiac artifacts. In each subject and at all balloon levels, the ΔPes versus ΔPt relationship virtually was superimposed on a breath-by-breath basis. However, the ΔPes/ΔPt ratio was not always close to unity, as indicated in table 1, which summarizes the results obtained in all 10 subjects, at the four balloon positions studied.

Five subjects had their optimum ΔPes/ΔPt ratio (0.98, 0.99, 0.96, 1.0, 1.0) when the balloon top was 5 cm from the cardia.

With the balloon 10 cm from the cardia, four individuals had their optimum ΔPes/ΔPt ratios (0.96, 1.0, 1.0, 0.96), and three had acceptable ratios of 0.92, 1.07, and 0.95, respectively. The remaining three subjects had ΔPes/ΔPt ratios far from the ideal (1.2, 0.6, 0.75). Only two subjects had their optimum ΔPes/ΔPt ra-
FIG. 2. Tracing of esophageal (Pes) versus tracheal pressure (Pt) during an occlusion test. ΔPes is of the same magnitude as ΔPt and in phase with it. Deviations from the line of identity (broken line) result from cardiac artifacts. Balloon level: 10 cm above cardia; Subject 6.

tios at 15 cm from the cardia. One of these (Subject 1) also had an acceptable ratio at 10 cm from the cardia (0.92), while the other one (Subject 9) had an acceptable ΔPes/ΔPt ratio only at this balloon position.

No subject had an acceptable ΔPes/ΔPt ratio with the balloon 20 cm from the cardia.

Table 2 lists the magnitude of the cardiac artifact in all subjects at each balloon level. Statistical analysis showed that the cardiac artifact did not change significantly with balloon position, although individually there were substantial changes with balloon level.

**Table 2. Changes in Esophageal Pressure (cm H$_2$O) due to Cardiac Artifact in 10 Subjects at Four Balloon Levels**

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<thead>
<tr>
<th>Subject No.</th>
<th>Balloon Level (cm from the Cardia)</th>
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<td>2</td>
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<td>3</td>
<td>3.5</td>
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<td>4</td>
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<td>5</td>
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<td>6</td>
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<td>9</td>
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<td>10</td>
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<td>Mean</td>
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<td>SD</td>
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**Discussion**

Esophageal pressure generally is used as a measure of pleural pressure. The balloon top conventionally is positioned 10 cm from the cardia.

The measurement of ΔPes/ΔPt ratio during an occluded inspiratory effort allows the reliability of the esophageal balloon technique to be tested. During such a maneuver, the changes in pleural pressure should be identical to changes in tracheal pressure, apart from a negligible difference resulting from thoracic gas rarefaction.14 If the esophageal pressure changes are close to those in tracheal pressure, then esophageal balloon measurements are a valid measure of the changes in pleural surface pressure.

Baydur et al.6 found that in awake subjects they could reliably estimate pleural pressure with an esophageal balloon (10 cm from the cardia) in the sitting and lateral positions, but in the supine position, two of their 10 subjects had unacceptable ΔPes/ΔPt ratios. In these two subjects, however, they were able to obtain acceptable ΔPes/ΔPt ratios by repositioning the balloon in the esophagus.

We measured the ΔPes/ΔPt ratio in anesthetized supine subjects using the occlusion test with the balloon positioned 5, 10, 15, 20 cm from the cardia. Our results show that with the balloon conventionally positioned (10 cm from cardia), the difference between ΔPes and ΔPt was less than 10% in most (seven out of 10) of the subjects. In the remaining three individuals, the ΔPes/
ΔPt ratios were unacceptable. However, by repositioning the balloon, acceptable ratios were obtained also in these three subjects (i.e., the difference between ΔPes and ΔPt was within 10%).

With the balloon optimally positioned in each subject, the average ΔPes/ΔPt ratio (±SD) amounted to 0.98 (±0.03).

Measurement of the mechanical properties of the lungs may become problematic in the presence of large cardiac artifacts. In our subjects, the optimum balloon positions did not always correspond to the locus of minimum cardiac artifact. The same was true for the conventional balloon position (10 cm from the cardia). Indeed, in the latter position, the cardiac artifact ranged between 4 and 7 cm H2O in three individuals. In all of these subjects, however, by repositioning the balloon, a smaller cardiac artifact could be obtained while maintaining an acceptable ΔPes/ΔPt ratio.

References