ORIGINAL ARTICLE

# Ultrasound Identification of Diaphragm by Novices Using ABCDE Technique

*Jaasmit Khurana, BSc,* Stephanie C. Gartner, BSc,* Latha Naik, MBBS,* and Ban C.H. Tsui, MD†*

**Background and Objectives:** In this study, we examined the consistency, rapidity, and reproducibility of the ABCDE technique for diaphragm identification. Operators using this method place the probe at the **A**nterior axillary line, watch for **B**reathing (lung sliding), and then move the probe **C**audally to identify the **D**iaphragm for **E**xamination.

**Methods:** A convenience sample of 100 patients was recruited from the preadmission clinic. Two novice operators each scanned the diaphragm using a linear ultrasound transducer in B-mode. Both operators completed the examination on all participants using the ABCDE technique, their times were averaged, and clinical success was defined as identification of the diaphragm in less than 2 minutes.

**Results:** An average of 33.7 seconds was taken to scan and identify the right hemidiaphragm (RD) (median, 25 seconds; 95% confidence interval, 28.8–38.5 seconds) with a 98% clinical success ratio, and an average of 46.9 seconds was taken to identify the left hemidiaphragm (LD) (median, 39.5 seconds; 95% confidence interval, 40.2–53.6 seconds) with a 97% clinical success ratio. In patients with a body mass index (BMI) of less than 30 kg/m$^2$, a 100% success ratio was seen when scanning the RD and 97% when scanning the LD. For those with a BMI of 30 kg/m$^2$ or greater, a 94% success rate was seen when scanning the RD and 97% when scanning the LD. No clinically significant differences were found between the times required for scanning either side of the diaphragm, regardless of the BMI.

**Conclusions:** The ABCDE technique demonstrates a fast, reliable, and simple method in which ultrasound can be used to visualize the diaphragm.

(*Reg Anesth Pain Med* 2018;43: 161–165)

Surveillance and measurement of diaphragmatic movement are important diagnostic tools for the assessment of its function.[1] Early detection of abnormal diaphragmatic movement may be important in monitoring and detecting potential adverse events from interscalene and supraclavicular blocks, which result in diaphragmatic paresis in 92% and 65% of cases, respectively.[2] In addition, dynamic ultrasound (US) imaging of the diaphragm can also assess any diaphragmatic dysfunction in critically ill patients.[3] Several imaging techniques have been used to identify the diaphragm, including fluoroscopy, magnetic resonance imaging, plethysmography, and US. Fluoroscopy mainly provides qualitative information regarding diaphragm movement, and involves radiation exposure and patient transportation.[4] Magnetic resonance imaging can derive useful quantitative and qualitative assessments of diaphragmatic excursion; however, it is limited because of the need for patient transportation and high costs.[5,6] Plethysmography is time consuming and uncomfortable for patients.[7]

Ultrasound can provide a real-time and noninvasive way to assess diaphragmatic function. Through various B- and M-mode US techniques, one can visualize diaphragmatic and lung motion in a real-time, portable, and bedside manner.[1,8] Such techniques, however, have been insufficiently detailed or provided inadequate views that were difficult to reproduce between patients.[1] Most current techniques use the acoustic windows of the liver and spleen to visualize the right hemidiaphragm (RD) and left hemidiaphragm (LD), respectively. These techniques, however, are time consuming and operator dependent and require significant expertise.[9] Recently, we reported a US-guided technique to evaluate diaphragmatic function without using acoustic windows.[10–12] This novel method, dubbed the "ABCDE" technique, visualizes the diaphragm via intercostal muscles. It is performed by placing the probe at the **A**nterior axillary line, watching for **B**reathing (lung sliding), then moving **C**audally to identify the **D**iaphragm for **E**xamination. During inspiration, the diaphragm is observed for thickening, which indicates that it is shortening and contracting.[9,13]

We hypothesize that the ABCDE method will be fast, reliable, and reproducible in identifying the diaphragm on both sides because of its obvious visualization of internal structures via intercostal spaces instead of traditional splenic and hepatic acoustic windows. Our primary objective was to examine the learning curves of the novice operators performing the ABCDE technique, indicated by the average of the speeds at which they completed examinations on each patient. Secondary objectives included evaluation of the impact of right- versus left-sided variation and body mass index (BMI) on the time taken to identify the diaphragm.

## METHODS

### Selection and Description of Participants

After approval by the research ethics board at the University of Alberta, a convenience sample of 100 patients (52 females and 48 males) ranging between the ages of 21 and 94 years was recruited between May 9, 2016, and June 26, 2016, in the preadmission clinic at the University of Alberta Hospital. Individuals unable to give written informed consent and those who refused to participate were excluded from the study. No fasting or any other preparation was required. After obtaining written informed consent, the following data were collected: sex, age, weight, height, BMI, American Society of Anesthesiologists Physical Status classification, and preexisting conditions. Participants then underwent LD and RD US scans during normal breathing. This article adheres to the applicable Equator guidelines.

From the *Department of Anesthesiology and Pain Medicine, University of Alberta, Edmonton, Alberta, Canada; and †Department of Anesthesiology, Perioperative and Pain Medicine, Stanford University, Stanford, CA.
Accepted for publication September 2, 2017.
Address correspondence to: Ban C.H. Tsui, MD, Department of Anesthesiology, Perioperative and Pain Medicine, Stanford University School of Medicine, 300 Pasteur Dr, H3582, Stanford, CA 94305 (e-mail: bantsui@stanford.edu).
This work was attributable to the Department of Anesthesiology and Pain Medicine, University of Alberta, Edmonton, Alberta, Canada.
B.C.H.T. is supported by a Clinical Scholar Award from the Alberta Heritage Foundation for Medical Research, Alberta, Canada; and J.K. is supported in part by an Alberta Health Services Surgery Strategic Clinical Network Summer Surgical Research Studentship Award, Alberta, Canada.
The authors declare no conflict of interest.
Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.rapm.org).

ISSN: 1098-7339
DOI: 10.1097/AAP.0000000000000718

## Technical Information

A General Electric LOGIQ E (Chicago, Illinois) machine was used at a starting depth of 4 cm with appropriate total gain using an 8- to 12-MHz linear transducer. Before each examination, all subjects were asked to lie in a semirecumbent position. In B-mode, a longitudinal scan was performed. Our ABCDE evaluation approach involved first placing the 12-RL probe along the anterior **A**xillary line just below the level of the nipple. The movement of the pleura on top of the diaphragm was visualized between the 2 ribs during normal **B**reathing. The probe was moved **C**audally along the anterior axillary line to identify **D**iaphragmatic thickening, where it was no longer hidden under the pleura during inspiration, for **E**xamination. The diaphragm was easily distinguished from the adjacent intercostal muscles with visualization of the pleura just superficial to the diaphragm. The operators visually examined the diaphragmatic muscle for the presence of a change in thickness on both the right (Fig. 1A; Video, Supplemental Digital Content 1, http://links.lww.com/AAP/A233) and left (Fig. 1B; Video, Supplemental Digital Content 2, http://links.lww.com/AAP/A234) sides during breathing. Two university students (one enrolled in an undergraduate kinesiology program and the other in first year of medicine), with no previous exposure to US or its use, each performed the US scans on each subject, and the times taken to obtain images of each hemidiaphragm were recorded. Operators were not able to view one another when performing the technique on any subject. Timing began when the probe first contacted the skin. Lung sliding was then examined by asking the participant to take deep breaths. The probe was then moved caudally, and when diaphragmatic thickening was clearly visualized in the zone of apposition, the timer was stopped. After consulting with several anesthesiologists, a target performance time of less than 2 minutes was deemed to be appropriate for practical application. Consequently, clinical success was defined as identification of the diaphragm in 2 minutes or less. An independent and experienced anesthesiologist was present to ensure that correct timing procedures took place and reviewed all recorded images afterward to confirm adequate quality based on the presence of the borders of the diaphragm muscle.

## Statistical Analysis

This is a prospective observational study. Statistical test results were obtained using computed, conventional techniques (Microsoft Office Excel 2011, Microsoft, Mountain View, California) and SPSS Statistics (SPSS version 20, IBM Cooperation, Armonk, New York). A statistical evaluation using confidence intervals (CIs) was performed to determine whether significant differences existed between time needed to scan the left and right sides. These results were reported as median with a 95% CI. Finally, to determine statistical significance for BMI, a dichotomy was performed (BMI <30 vs ≥30 kg/m$^2$) followed by a Mann-Whitney $U$ test. Interrater reliability was assessed with Cohen κ coefficient.

# RESULTS

A total of 100 participants were recruited, and all participants had their diaphragms successfully located using the ABCDE US method by both novice operators. Three participants were excluded from statistical analysis as a result of missing time information due to technical error. Thus, our study includes data from 97 of 100 consented participants. The quality of all images was judged to be adequate by an anesthesiologist. No adverse events or complications resulted during this study. Specific demographic and anthropometric data can be found in Table 1.

Using a clinical success benchmark, signified by identification of the diaphragm in 2 minutes or less, success was achieved in 98% of RD trials and 97% of LD trials. Figure 2 displays these success rates using the averaged results of operators A and B. In terms of actual time, an average of 33.7 seconds was taken to scan the RD (median, 25 seconds; 95% CI, 28.8–38.5 seconds), and an average of 46.9 seconds was taken to scan the LD (median, 39.5 seconds; 95% CI, 40.2–53.6 seconds).

Body mass index data were missing from 2 of the 97 participants because of absence of chart information and could not be obtained. Figure 3 represents the relationship between various BMIs and successes and failures achieved for the remaining 95 patients. In those with a BMI of less than 30 kg/m$^2$ (62 participants), a 100% success ratio was seen when scanning the RD and 97% when scanning the LD. For those with a BMI of 30 kg/m$^2$ or greater, a 94% success rate was seen when scanning the RD and 97% when scanning the LD.

The learning curve was determined by comparing the average time needed by the 2 operators to scan the patient, and the patient order number, to see if a correlation existed. The data were then displayed on a scatterplot, and a trend line was superimposed. Data from each side were examined independently. An almost negligible decline in the average times taken was seen when scanning the LD and RD throughout the course of the study. Figure 4 displays the learning curve.

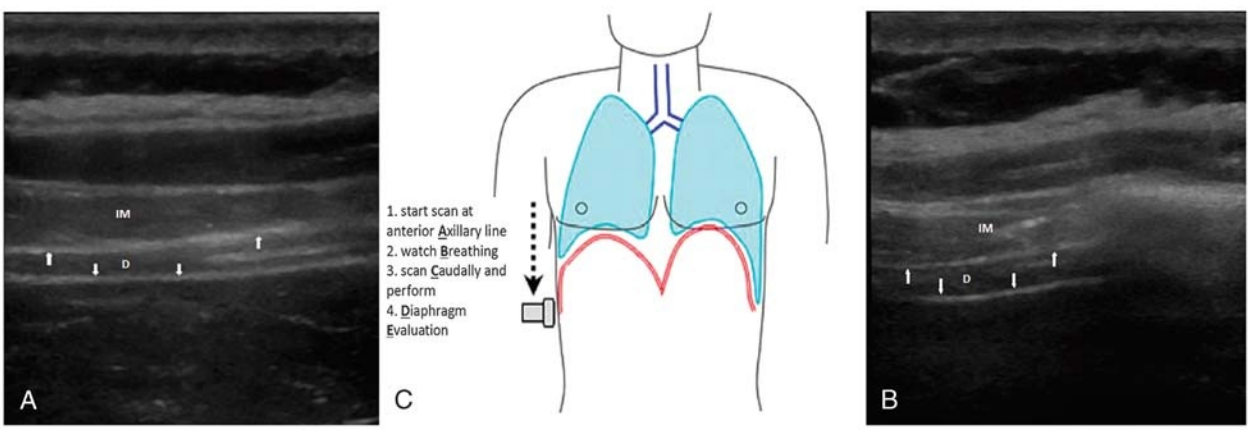


**FIGURE 1.** B-mode US image of the diaphragm using the ABCDE method. A, Inhalation demonstrated by thickening of the right diaphragm. B, Inhalation demonstrated by thickening of the left diaphragm. C, Schematic of the technique demonstrated by probe placement and movement.[8] D indicates diaphragm; IM, intercostal muscle. Arrows indicate border of the diaphragm.

**TABLE 1.** Demographic and Anthropometric Data of All Participants

| Characteristics | Value |
|---|---|
| Studied, n | 100 |
| Sex (M/F), n | 52/48 |
| Age, y | 56.9 ± 14.3 (21–94) |
| Weight, kg | 81.7 ± 19.7 (46–133.8) |
| Height, cm | 169.4 ± 9.7 (148–200) |
| BMI, kg/m$^2$ | 28.8 ± 6.7 (17.9–48.8) |

Based on 95% CIs, the difference in time taken to scan the right and left sides was not clinically significant. A Mann-Whitney $U$ test indicated that the time taken to scan the RD was statistically larger in subjects with a BMI of 30 kg/m$^2$ or greater ($P = 0.000$) than in those with a BMI of less than 30 kg/m$^2$ ($P = 0.048$). However, no other statistically significant difference in scanning time was seen when comparing findings for those subjects in different BMI categories. An interrater reliability analysis using the κ statistic was performed to determine consistency between the 2 raters in achieving clinical success. When scanning the RD, κ = 1.00, and when scanning the LD, κ = 0.99. These values indicate a very high level of agreement between operators.

## DISCUSSION

This is the first study to determine whether the ABCDE US technique is a practical approach for novices to visualize the diaphragm. Unlike previously described techniques, this technique has a high degree of success that is independent of the diaphragm side scanned and BMI and requires minimal expertise.

The use of US to assess diaphragmatic function has been used because of its real-time, noninvasive, and low-cost nature.[14] Despite its extensive use, however, current US techniques remain less than ideal for diagnostic purposes because of their complexity and extensive time requirements.[1] There is only limited information available concerning learning curves and times needed to perform diaphragmatic examination. The study of Testa et al[1] was the only reported study that explicitly documented the time taken to scan the diaphragm. In their study, it was reported that by transversely scanning the subcostal anterior area, an experienced sonographer took an average of nearly 10 minutes to identify the RD, whereas an inexperienced sonographer averaged 17 minutes with associated significant interobserver variability.[1] When obtaining images through hepatic and splenic acoustic windows, it is not uncommon for even the most experienced sonographer to take a prolonged time to identify the diaphragm. This is due to great limitations posed by using the small acoustic windows. Visualization through the splenic window is especially difficult because of the intervening gastric contents and stomach.[7,13,15] In fact, Testa et al[1] were unable to provide the average time needed to scan the LD because their standardized technique was not consistently successful in obtaining acceptable images.

Our approach seems to be more efficient in the identification of the diaphragm than any previously described. First, it may be partly due to the utilization of intercostal spaces rather than the splenic or hepatic acoustic windows. In contrast to challenging methods using the acoustic windows, our technique simply uses external landmarks such as the nipple and the anterior axillary line. Second, using B-mode with a stepwise "dynamic" approach, one can easily observe the sliding movement of the pleura into the zone of apposition above the diaphragm muscle as "readily identifiable landmarks" to locate the diaphragm. This method contrasts previous "static" approaches, including those that begin by placing the probe at certain fixed locations such as at the 9th or 10th intercostal spaces.[13] Using a "static" approach, it can be more challenging for novices to know exactly where to place the probe, especially in obese patients. More importantly, such a "static" approach also neglects the fact that the diaphragm may be situated higher (eg, diaphragm paralysis) or lower (eg, chronic obstructive pulmonary disease) than these fixed external landmarks because of underlying pathologic state.

Indeed, our 2 novice operators experienced great success at visualizing the diaphragm in less than 2 minutes using this technique. In addition, the times did not significantly differ between the left and right sides. The 95% CIs for each hemidiaphragm were 28.8 to 38.5 seconds for the RD and 40.2 to 53.6 seconds for the LD, respectively. After consulting several anesthesiologists, it was deemed that a difference of less than 20 seconds between the upper boundaries of the CIs for both sides and less than 20 seconds between the lower boundaries of the CIs for both sides would be clinically insignificant. Therefore, it was found that the difference in time taken to scan the right and left sides was not clinically significant.

Figure 3 displays that no clear relationship exists between participant BMI and success rates for diaphragmatic scanning. It was determined, however, that scanning the RD for a participant with BMI of 30 kg/m$^2$ or greater took statistically longer than in those with BMI of less than 30 kg/m$^2$. Despite this result, clinical significance remains minimal as only 6% (2/33) of the total right-sided scans where BMI is 30 kg/m$^2$ or greater required longer than 2 minutes to be identified and assessed. The 2 outlying RD scan times were 140 and 150 seconds, which are only slightly greater than the target of 120 seconds. The statistically longer time to scan the right sides of patients with BMI of 30 kg/m$^2$ or greater likely arose because of the ease and quickness with which the operators could scan those with a BMI of less than 30 kg/m$^2$. Overall, we found no clinical correlation between BMI and performance time, and both hemidiaphragms were scanned within a clinically appropriate time frame irrespective of BMI. Moreover, our study demonstrated that no significant learning curve is present in the mastery of this simple technique. For a learning curve to exist, clear improvement should be seen while repeatedly implementing a technique until a constant level of success is established.[16] This pattern, however, is not shown in Figure 4, where, despite the presence of slight

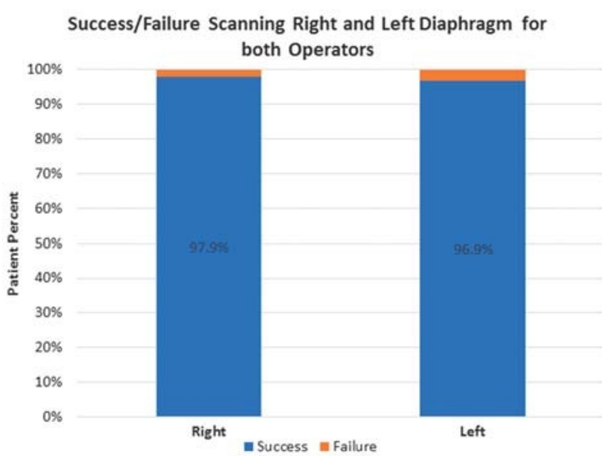


**FIGURE 2.** Representation of success (scanning time <2 minutes) and failure (scanning time >2 minutes) based on the averaged scanning times of the 2 novice operators. Exact percentages of successes are listed in the figure.

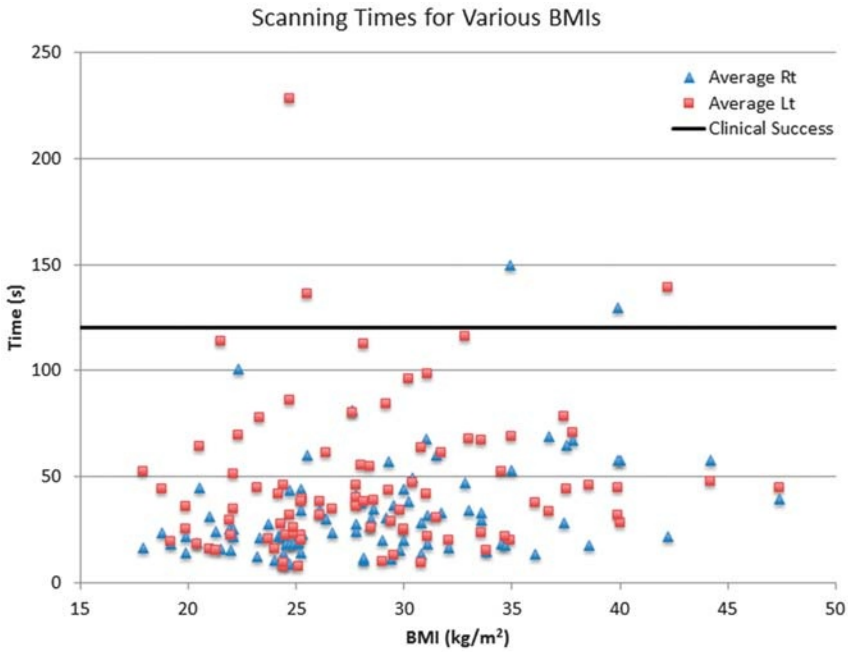


**FIGURE 3.** Representation of the successes and failures achieved in scanning patients with various BMIs. The horizontal bold line represents the cut-ff time required (120 seconds) to scan for clinical success to be established.

downward trend lines, there is no significant difference in the times required to scan participants from the start to the end of the study. No plateau is present on either side scanned, which shows that clinical success can be consistently achieved without practicing on numerous patients.

A limitation of our study is that we do not directly compare our technique with those using the acoustic windows. Despite this, our study suggests that the ABCDE technique is an efficient and accurate method to identify the diaphragm. In addition, this standardized approach requires minimal expertise and can easily be implemented to have clinically significant results for patients. Future studies will be needed to determine the merit of this technique on patients with a paralyzed diaphragm and assess its function based on parameters such as changes in diaphragmatic muscle thickness and its movement. Additional studies would be important to examine the internal and external reliability.

## ACKNOWLEDGMENTS

*The authors thank Dr Luke Murtha for his contribution to the study.*

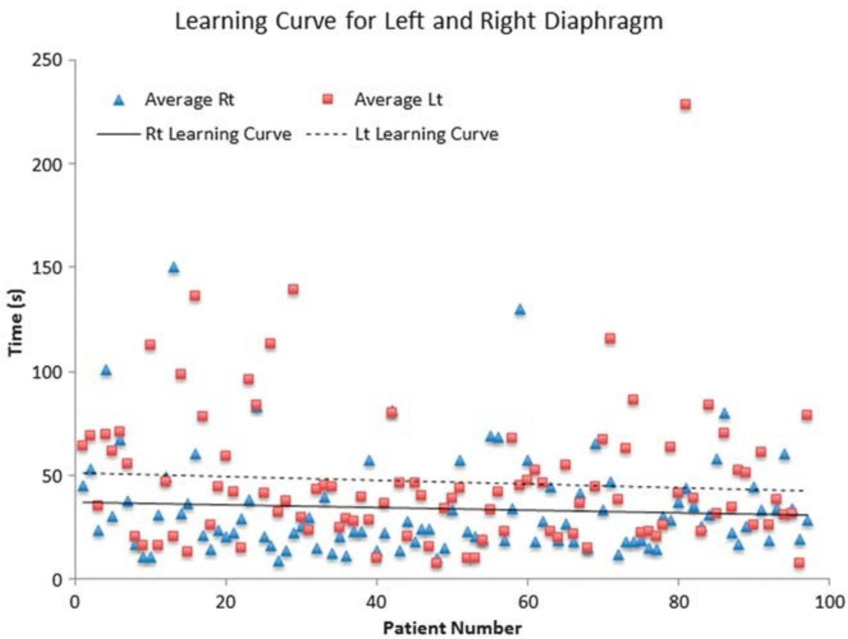


**FIGURE 4.** Graphical representation of the learning curves for both the right (solid line) and left (dashed line) diaphragms. The *x* axis represents patient-number order from the beginning to the end of the study. No significant trends were observed.

## REFERENCES

1. Testa A, Soldati G, Giannuzzi R, Berardi S, Portale G, Gentiloni Silveri N. Ultrasound M-mode assessment of diaphragmatic kinetics by anterior transverse scanning in healthy subjects. *Ultrasound Med Biol*. 2011;37:44–52.
2. Kim BG, Han JU, Song JH, Yang C, Lee BW, Baek JS. A comparison of ultrasound-guided interscalene and supraclavicular blocks for post-operative analgesia after shoulder surgery. *Acta Anaesthesiol Scand*. 2017;61:427–435.
3. Zambon M, Greco M, Bocchino S, Cabrini L, Beccaria PF, Zangrillo A. Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: a systematic review. *Intensive Care Med*. 2017;43:29–38.
4. Houston JG, Angus RM, Cowan MD, McMillan NC, Thomson NC. Ultrasound assessment of normal hemidiaphragmatic movement: relation to inspiratory volume. *Thorax*. 1994;49:500–503.
5. Kiryu S, Loring SH, Mori Y, Rofsky NM, Hatabu H, Takahashi M. Quantitative analysis of the velocity and synchronicity of diaphragmatic motion: dynamic MRI in different postures. *Magn Reson Imaging*. 2006;24:1325–1332.
6. Kolar P, Neuwirth J, Sanda J, et al. Analysis of diaphragm movement during tidal breathing and during its activation while breath holding using MRI synchronized with spirometry. *Physiol Res*. 2009;58:383–392.
7. Scott S, Jonathan FP, Carter R, McEntegart M, MacFarlane NG. Diaphragm ultrasonography as an alternative to whole-body plethysmography in pulmonary function testing. *J Ultrasound Med*. 2006;25:225–232.
8. Boon AJ, O'Gorman C. Ultrasound in the assessment of respiration. *J Clin Neurophysiol*. 2016;33:112–9.
9. Kharma N. Dysfunction of the diaphragm: imaging as a diagnostic tool. *Curr Opin Pulm Med*. 2013;19:394–8.
10. Naik LY, Sondekoppam RV, Jenkin Tsui J, Tsui BC. An ultrasound-guided ABCDE approach with a sniff test to evaluate diaphragmatic function without acoustic windows. *Can J Anesth*. 2016;63:1199–1200.
11. Tsui JJ, Tsui BC. A novel systematic ABC approach to diaphragmatic evaluation (ABCDE). *Can J Anaesth*. 2016;63:636–637.
12. Tsui BC, Tsui J. ABC Diaphragmatic evaluation for neonates. *Paediatr Anaesth*. 2016;26:768–769.
13. Goligher EC, Laghi F, Detsky ME, et al. Measuring diaphragm thickness with ultrasound in mechanically ventilated patients: feasibility, reproducibility and validity. *Intensive Care Med*. 2015;41:642–649.
14. American College of Emergency Physicians. ACEP Policy Statements Emergency Ultrasound Guidelines; 1–38. Available at: http://www.acep.org/WorkArea/DownloadAsset.aspx?id=32878. Accessed July 1, 2016.
15. Ayoub J, Cohendy R, Prioux J, et al. Diaphragm movement before and after cholecystectomy: a sonographic study. *Anesth Analg*. 2001;92:755–761.
16. Schlachta CM, Mamazza J, Seshadri P, Cadeddu M, Gregoire R, Poulin EC. Defining a learning curve for laparoscopic colorectal resections. *Dis Colon Rectum*. 2001;44:217–222.