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ORIGINAL ARTICLE

Accuracy of chest auscultation in detecting abnormal respiratory mechanics in the immediate postoperative period after cardiac surgery

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ABSTRACT

Objective: To investigate the accuracy of chest auscultation in detecting abnormal respiratory mechanics. **Methods:** We evaluated 200 mechanically ventilated patients in the immediate postoperative period after cardiac surgery. We assessed respiratory system mechanics - static compliance of the respiratory system (C_{st},rs) and respiratory system resistance (R,rs) - after which two independent examiners, blinded to the respiratory system mechanics data, performed chest auscultation. **Results:** Neither decreased/abolished breath sounds nor crackles were associated with decreased C_{st},rs (≤ 60 mL/cmH_2O), regardless of the examiner. The overall accuracy of chest auscultation was 34.0% and 42.0% for examiners A and B, respectively. The sensitivity and specificity of chest auscultation for detecting decreased/abolished breath sounds or crackles were 25.1% and 68.3%, respectively, for examiner A, versus 36.4% and 63.4%, respectively, for examiner B. Based on the judgments made by examiner A, there was a weak association between increased R,rs (≥ 15 cmH_2O/L/s) and rhonchi or wheezing ($\varphi = 0.31$, $p < 0.01$). The overall accuracy for detecting rhonchi or wheezing was 89.5% and 85.0% for examiners A and B, respectively. The sensitivity and specificity for detecting rhonchi or wheezing were 30.0% and 96.1%, respectively, for examiner A, versus 10.0% and 93.3%, respectively, for examiner B. **Conclusions:** Chest auscultation does not appear to be an accurate diagnostic method for detecting abnormal respiratory mechanics in mechanically ventilated patients in the immediate postoperative period after cardiac surgery.

Keywords: Diagnostic tests, routine; Physical examination; Respiratory sounds; Respiratory mechanics; Data accuracy; Respiration, artificial.

INTRODUCTION

Chest auscultation performed with a traditional (acoustic) stethoscope is a practical, inexpensive method of diagnosing and monitoring abnormalities of the respiratory system in clinical practice.[1-3] Although routinely used by health care professionals for the evaluation of patients with cardiopulmonary disorders, chest auscultation has some important limitations: it is a subjective tool; it requires good hearing acuity and a high level of experience on the part of the health care professional in order to detect adventitious sounds[4]; the nomenclature for respiratory sounds is not standardized[5]; acoustic stethoscopes are not ideal instruments to detect respiratory sounds because they can modify sounds within the spectrum of clinical interest[6]; and there is significant interobserver variability.[7] Despite those limitations, chest auscultation is presently applied to assess the respiratory function of mechanically ventilated patients and the findings are therefore employed in the decision-making process for patient care. However, abnormal respiratory sounds might not reflect impaired respiratory function or abnormal respiratory mechanics, and abnormalities in respiratory mechanics do not necessarily translate into audible sounds. Therefore, chest auscultation might not provide accurate information about the mechanical properties of the respiratory system.

We hypothesized that chest auscultation findings would not show an association with the mechanical properties of the respiratory system in mechanically ventilated patients. Therefore, the aim of this study was to investigate the accuracy of chest auscultation as a diagnostic method to detect abnormalities in respiratory mechanics in mechanically ventilated patients in the immediate postoperative period after cardiac surgery.

METHODS

This was a cross-sectional study conducted at the Cardiac Surgery ICU of the *Instituto de Cardiologia do Distrito Federal*, in the Federal District of Brasília, Brazil. The local research ethics committee approved the

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study protocol, and all of the patients evaluated gave written informed consent prior to undergoing surgery.

From among consecutive adult patients undergoing cardiac surgery between January of 2013 and December 2013, we recruited 200 to participate in this study. We applied the following inclusion criteria: undergoing cardiac surgery for definitive or palliative treatment of heart disease, with or without cardiopulmonary bypass; having a Ramsay sedation scale score of 6; requiring continuous mechanical ventilation (volume- or pressure-controlled modes); and not receiving any vasoactive medication at the time of data collection. Patients who declined to participate in the protocol were excluded, as were those who were sent to the ICU with an open chest and those in whom the ventilator weaning process had already begun. The study design is shown in Figure 1.

Protocol

After the first 20 min of the immediate postoperative period, beginning at the arrival of the patient in the ICU, we assessed the mechanical properties of the respiratory system, after which we performed chest auscultation. The mechanical properties of the respiratory system were evaluated by end-inspiratory occlusion,[8] with patients in the supine position and without triggering the mechanical ventilator (Evita 2 or Evita 4; Dräger Medical, Lübeck, Germany). The following ventilator settings were used for the assessment of respiratory system mechanics: volume controlled continuous mandatory ventilation; a constant inspiratory flow rate (60 L/min); a tidal volume of 8 mL/kg (of the ideal weight); a positive end-expiratory pressure (PEEP) of 8 cmH_2O; an FiO_2 sufficient to maintain peripheral oxygen saturation above 95%; and an end-inspiratory pause of 3 s. To detect auto-PEEP, end-expiratory occlusion was performed.[9] Static compliance of the respiratory system (C_{st},rs) was obtained by the following formula:

tidal volume / elastic recoil pressure − [*PEEP* + *auto-PEEP*]

To obtain the respiratory system resistance (R,rs), we used this formula:

[*peak inspiratory pressure* − *elastic recoil pressure*] / *flow rate*

Reference values for C_{st},rs and R,rs[10] were adopted, a C_{st},rs < 60 mL/cmH_2O being considered below normal and an R,rs ≥ 15 cmH_2O/L/s being considered above normal.

After the assessment of respiratory system mechanics had been completed, chest auscultation was performed by two highly experienced ICU health care professionals (a physician and a physiotherapist), both of whom were blinded to the mechanics data and were working independently. The auscultation was performed with patients in the same position

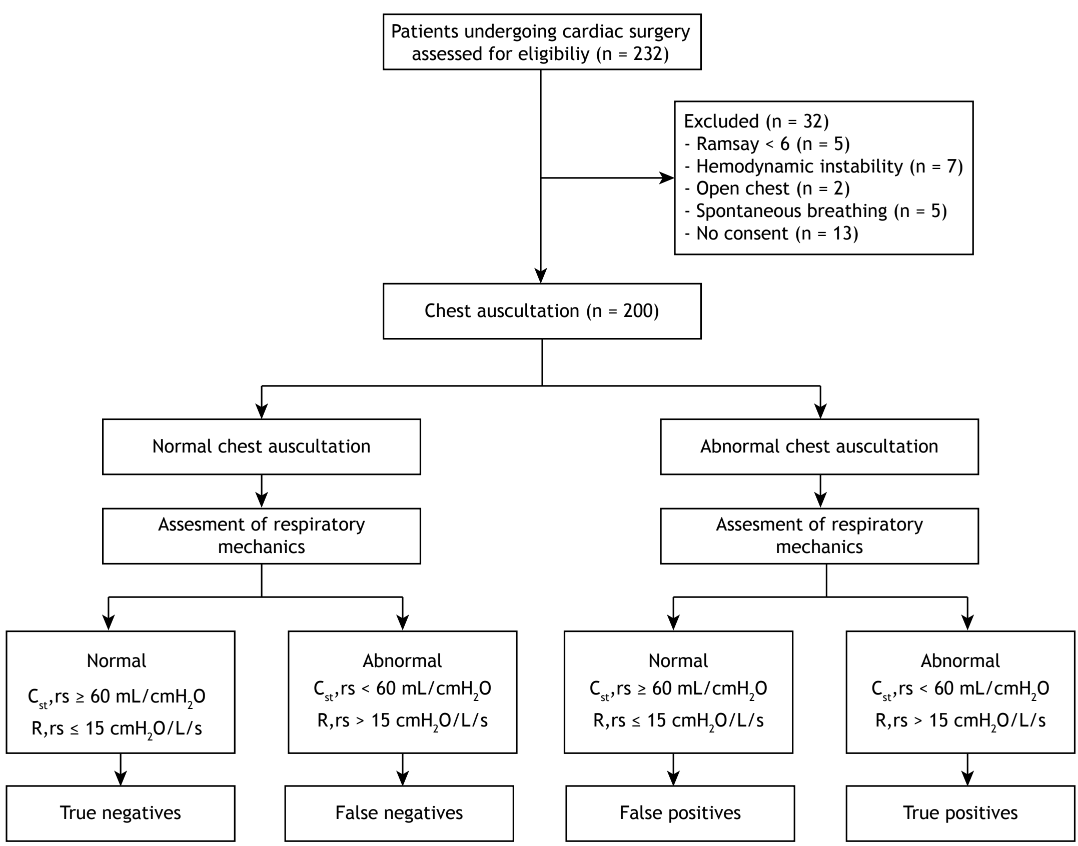

Figure 1. Study design. C_{st},rs: static compliance of the respiratory system; and R,rs: respiratory system resistance.

and with the same ventilator settings used in the previous assessment of the mechanical properties of the respiratory system (without the end-inspiratory pause), and both professionals used the same stethoscope (Littmann Classic II; 3M, St. Paul, MN, USA). To ensure consistency between the examiners, the skin was marked, on both sides, at the following sites: on the upper chest in the second intercostal space, along the midclavicular line; on the lateral chest between the fourth and fifth intercostal spaces, along the midaxillary line; and on the lower chest between the seventh and eighth intercostal spaces, along the midaxillary line.[11] Abnormal chest auscultation findings were defined as any abnormal sound (decreased breath sounds, crackles, rhonchi, or wheezing) heard at one or more of the six sites marked. Because the waveform analysis of the mechanical ventilator could influence examiner impressions, thereby skewing the chest auscultation results, examiners were instructed not to look at the mechanical ventilator display while they performed chest auscultation. Normal or decreased breath sounds and crackles were considered to be related to the lung parenchyma or chest wall, whereas rhonchi and wheezing were considered airway-related sounds.

Statistical analysis

The sample size calculation was performed by using PASS software, version 11.0 (NCSS, LLC, Kaysville, UT, USA), with the following parameters: diagnostic test sensitivity of 80%; a diagnostic test specificity of 90%; a 5% probability of a type I error; a diagnostic test power of 80%; and a 60% prevalence of abnormal respiratory system mechanics in the immediate postoperative period after cardiac surgery. Thus, the minimum sample size necessary was determined to be 178 subjects.

Student's t-tests for independent samples were used in order to determine whether C_{st},rs and R,rs were abnormal depending on how they were classified by each examiner on the basis of the chest auscultation findings. Chi-square tests or Fisher's exact tests were used in order to identify associations between chest auscultation variables and those related to respiratory mechanics. The accuracy of chest auscultation in representing alterations of the mechanical properties of the respiratory system was expressed as sensitivity, specificity, positive likelihood ratio, and negative likelihood ratio. Cohen's kappa statistic (κ) was determined in order to assess the interobserver agreement in chest auscultation, and the phi coefficient (φ) was calculated in order to test the strength of the correlations between the auscultation findings and the respiratory mechanics. Continuous variables are expressed as mean ± standard deviation, and categorical variables are expressed as absolute and relative values unless otherwise stated. Statistical analyses were performed with the SPSS Statistics software package, version 17.0 (SPSS Inc., Chicago, IL, USA), and the significance level was set at 5%.

RESULTS

We evaluated 200 patients (116 men) in the immediate postoperative period after cardiac surgery. Among the patients evaluated, the mean age was 56.9 ± 11.7 years and the mean body mass index was 26.8 ± 4.1 kg/m^2. The cardiac surgery procedures and patient respiratory comorbidities are shown in Table 1.

In the study sample, the mean C_{st},rs was 50.1 ± 18.3 mL/cmH_2O, and 41 (20.5%) of the 200 patients had a C_{st},rs value ≥ 60 mL/cmH_2O. According to examiner A, 147 (73.5%) of the patients had normal sounds related to the lung parenchyma or chest wall and C_{st},rs did not differ between the patients in whom such sounds were classified as normal and those in whom they were classified as abnormal (49.6 ± 18.3 mL/cmH_2O vs. 50.9 ± 22.7 mL/cmH_2O; p = 0.65). Examiner B categorized 127 (63.5%) of the patients as having normal sounds related to the lung parenchyma or chest wall and observed no significant difference in C_{st},rs, regardless of whether those sounds were classified as normal or abnormal on chest auscultation (49.7 ± 18.8 mL/cmH_2O vs. 50.3 ± 17.5 mL/cmH_2O; p = 0.82). The C_{st},rs data related to examiner A and examiner B are shown in Figures 2A and 2B, respectively.

In the study sample, the mean R,rs was 9.3 ± 3.8 cmH_2O/L/s and the R,rs was increased in 20 (10.0%) of the 200 patients. Examiner A found that the R,rs was significantly lower in the patients with normal auscultation than in those in whom there was rhonchi or wheezing (9.1 ± 3.6 cmH_2O/L/s vs. 12.5 ± 4.9 cmH_2O/L/s; p < 0.01). Examiner B categorized 187 (93%) of the patients as presenting no airway-related sounds and observed no significant difference in R,rs, regardless of whether those sounds were classified as normal or abnormal on chest auscultation (9.3 ± 3.8 cmH_2O/L/s vs. 8.4 ± 3.7 cmH_2O/L/s; p = 0.35). The R,rs data related to examiner A and examiner B are shown in Figures 2C and 2D, respectively.

Regarding C_{st},rs, the false-positive rates were 31.7% and 36.5% for examiners A and B, respectively, compared with 74.8% and 63.5%, respectively, for

Table 1. Cardiac surgery procedures and patient respiratory comorbidities.

Variable	(N = 200)
Cardiac surgery procedures, n (%)	
Myocardial revascularization	139 (69.5)
Heart valve replacement	50 (25.0)
Aortic repair	5 (2.5)
Atrial septal repair	3 (1.5)
Heart valve repair	2 (1.0)
Intracardiac tumor resection	1 (0.5)
Respiratory comorbidities, n (%)	
None	141 (70.5)
Nicotine addiction	52 (26.0)
COPD	5 (2.5)
Tuberculosis sequelae	2 (1.0)

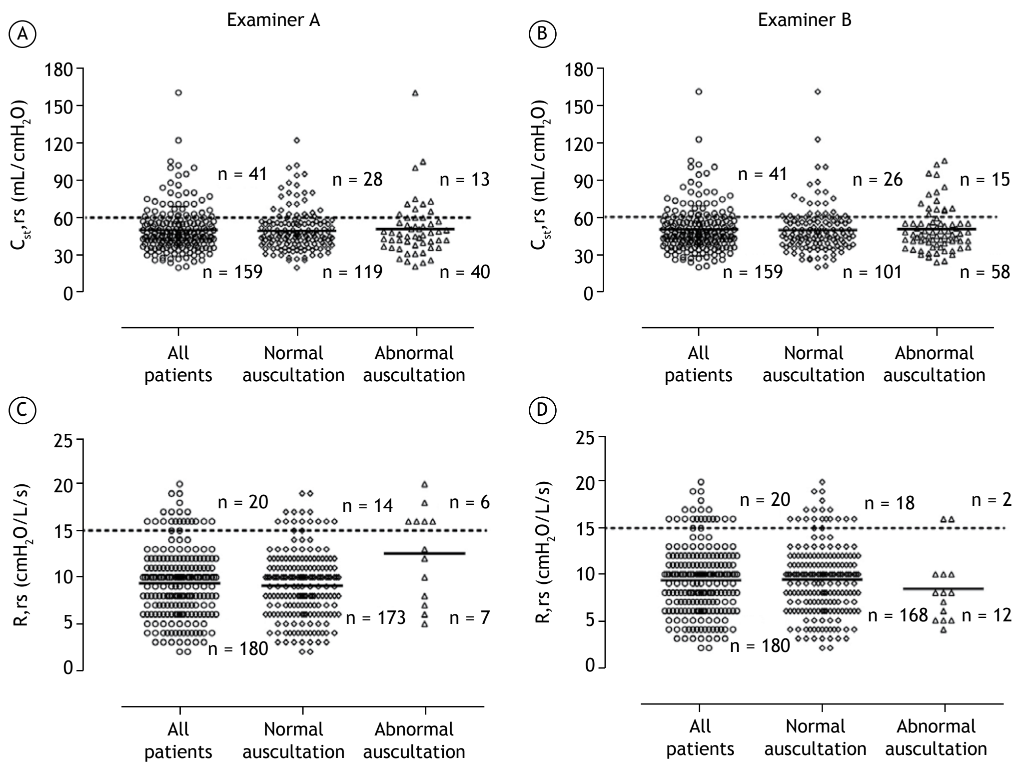

Figure 2. A and B: static compliance of the respiratory system (C_{st},rs); C and D: respiratory system resistance (R,rs). Open circles represent individual values of C_{st},rs and R,rs; open diamonds represent individual values of C_{st},rs and R,rs when examiners classified chest auscultation as normal; open triangles represent individual values of C_{st},rs and R,rs when examiners classified chest auscultation as abnormal; dotted horizontal lines mark the cut-off values for C_{st},rs (≥ 60 mL/cmH_2O) and R,rs (≤ 15 $cmH_2O/L/s$); and solid horizontal lines are the mean C_{st},rs and R,rs values for each chest auscultation classification.

Table 2. Association between sounds related to the lung parenchyma or chest wall and static compliance of the respiratory system.

Variable		C_{st},rs (mL/cmH_2O) < 60 (n)	≥ 60 (n)	p	φ	φ p
Decreased breath sounds, abolished breath sounds, or crackles			Examiner A			
	Yes	40	13	0.39	0.03	0.66
	No	119	28			
			Examiner B			
	Yes	58	15	0.99	0	0.99
	No	101	26			

C_{st},rs: static compliance of the respiratory system; and φ: phi coefficient.

the false-negative rates. decreased/abolished breath sounds nor crackles were associated with decreased C_{st},rs, regardless of the examiner (Table 2). When diminished breath sounds and crackles were analyzed separately, decreased C_{st},rs was not associated with either (p = 0.71 and p = 0.37, respectively, for examiner A; and p = 0.39 and p = 0.86, respectively, for examiner B).

For R,rs (Table 3), examiners A and B had false-positive rates of 3.8% and 6.6%, respectively, and false-negative rates of 70% and 90%, respectively. As can be seen in Table 3, there was a weak positive association between rhonchi/wheezing, as reported by examiner A, and increased R,rs (φ = 0.31; p < 0.01), although no such association was observed for examiner B (φ = 0.03; p = 0.63). In addition, airway-related sounds were not associated with the presence of auto-PEEP (p = 0.41 and p = 0.46 for examiners A and B, respectively).

When performed by examiner A, chest auscultation had a sensitivity and specificity of 25.1% and 68.3%, respectively, for the detection of abnormal sounds related to the lung parenchyma or chest wall and of 30.0% and 96.1%, respectively, for the detection of abnormal airway-related sounds. When performed by examiner B, chest auscultation had a sensitivity and specificity of 36.4% and 63.4%, respectively, for the detection of abnormal sounds related to the lung parenchyma or chest wall, compared with 10.0% and 93.3%, respectively, for the detection of abnormal airway-related sounds. Other values related to the accuracy of chest auscultation in detecting abnormal respiratory mechanics are shown in Table 4.

In 177 patients, the two examiners agreed that there were no airway-related sounds, whereas they agreed that there were airway-related sounds in 4 patients. However, examiner A categorized 9 patients as presenting airway-related sounds, whereas examiner B categorized those same patients as not presenting such sounds. Similarly, examiner A categorized 10 patients as not presenting airway-related sounds, whereas examiner B categorized those same patients as presenting such sounds. For airway-related sounds, there was fair agreement between the two examiners (κ = 0.245; 95% CI: 0.040 to 0.512; p < 0.01). For sounds related to the lung parenchyma or chest wall, the two examiners agreed regarding the detection of normal sounds in 94 patients and regarding the detection of abnormal sounds in 20 patients. However, in 33 patients, the sounds related to the lung parenchyma or chest wall were classified as abnormal by examiner A and normal by examiner B. In another 53 patients, such sounds were classified as normal by examiner A and abnormal by examiner B. For sounds related to the lung parenchyma or chest wall, there was no agreement between the two examiners (κ = 0.015; 95% CI: −0.123 to 0.164; p = 0.82).

DISCUSSION

Here, we have provided data on the utility of chest auscultation for detecting mechanical abnormalities of the respiratory system in mechanically ventilated patients in the immediate postoperative period after cardiac surgery. We showed that neither the presence nor the absence of abnormal respiratory sounds was associated with mechanical abnormalities of the respiratory system, and that chest auscultation failed to accurately identify patients with abnormal respiratory mechanics.

Less than one third of the patients evaluated in the present study had lung disease or were addicted to nicotine prior to undergoing surgery. Such patients could present some degree of abnormality in respiratory mechanics. In fact, in the immediate postoperative period, C_{st},rs was decreased in 79.5% of those patients and R,rs was increased in 10.0%.

Mechanical abnormalities of the respiratory system are well established in patients undergoing cardiac surgery.[12,13] A reduction in C_{st},rs can be attributed to surgery-related events affecting the elastic recoil pressure of the respiratory system, such as cardiopulmonary bypass and an inflammatory reaction to extracorporeal circulation[14]; the effects

Table 3. Association between airway-related sounds and respiratory system resistance.

Variable		R,rs ($cmH_2O/L/s$) ≥ 15 (n)	R,rs ($cmH_2O/L/s$) < 15 (n)	p	φ	φ p
Rhonchi or wheezing			Examiner A			
	Yes	6	7	< 0.01[a]	0.31	< 0.01
	No	14	173			
			Examiner B			
	Yes	2	12	0.63[a]	0.03	0.57
	No	18	168			

R,rs: respiratory system resistance; and φ: phi coefficient. [a]Fisher's exact test.

Table 4. Accuracy, sensitivity, specificity, positive likelihood ratio, and negative likelihood ratio for chest auscultation in detecting abnormal respiratory mechanics.

Examiner Variable	Accuracy (%)	Sensitivity % (95% CI)	Specificity % (95% CI)	LR+ Ratio (95% CI)	LR− Ratio (95% CI)
A					
Decreased breath sounds, abolished breath sounds, or crackles	34.0	25.2 (21.5-28.3)	68.3 (54.1-80.6)	0.8 (0.4-1.4)	1.1 (0.9-1.4)
Rhonchi or wheezing	89.5	30.0 (13.9-46.7)	96.1 (94.3-98)	7.7 (2.4-22.8)	0.7 (0.5-0.9)
B					
Decreased breath sounds, abolished breath sounds, or crackles	42.0	10.0 (1.8-28.6)	93.3 (92.4-95.4)	0.9 (0.6-1.7)	1.0 (0.7-1.3)
Rhonchi or wheezing	85.0	79.5 (71.2-86.2)	20.5 (15.7-24.7)	1.5 (0.2-6.2)	0.9 (0.7-1.0)

LR+: positive likelihood ratio; and LR−: negative likelihood ratio.

of muscle paralysis and anesthesia[15]; sternotomy, small airway closure, and lung volume reduction[16]; and the effects of pulmonary circulation on lung parenchyma stability.[17] The increase in R,rs may be due to several factors, such as secretion or fluid accumulation in the airway, airway edema, and time constant inequalities.[18]

The main finding of the present study was that chest auscultation has low accuracy in detecting abnormal respiratory mechanics in mechanically ventilated patients in the immediate postoperative period after cardiac surgery. Although examiner A had 89.5% accuracy in detecting increased R,rs, the mean R,rs among the patients in whom examiner A classified the airway-related sounds as abnormal was 12.5 ± 4.9 $cmH_2O/L/s$ (below the cutoff value for increased R,rs), which could therefore be a false-positive result.

The lack of an association between respiratory mechanics and chest auscultation could be attributed to technical and physiological factors. From a technical point of view, the respiratory sound spectrum can be modulated along its path from the sound source to the auditory cortex of the health care professional. That phenomenon is related to the unsuitability of acoustic stethoscopes as instruments for detecting respiratory sounds, because they can amplify and attenuate sound transmission within the spectrum of interest,[6] as well as to the fact that the chest wall can reduce the amplitude of sound transmission.[19] From a physiological perspective, respiratory sounds are generated in the large airways and in the tissues of the lung parenchyma/chest wall, being dependent on the airflow pattern, large airway patency, lung tissue stiffness/stability, permeability of the small airways, and the propensity of the airways to collapse.[20] Although the mechanisms of airway-related sound generation have yet to be fully elucidated, they clearly involve the movement of secretions, vibration of the airway walls,[21] and airflow limitation.[22,23] During the assessment of respiratory mechanics and the chest auscultation protocols, we administered air at a high flow rate (60 L/min), which could have favored the generation of sounds in the large airways. It can be argued that chest auscultation is still useful for detecting certain mechanical abnormalities of the respiratory system, such as airflow limitation. Kress et. al.[24] found that inspection/palpation and auscultation of the chest had a sensitivity, specificity, positive predictive value, and negative predictive value of 51%, 95%, 96%, and 46%, respectively, for detecting intrinsic PEEP (i.e., auto-PEEP) in mechanically ventilated patients. The difference between the findings of those authors and our findings, regarding the sensitivity of chest auscultation in detecting abnormal airway mechanics on the basis of airway-related sounds, could be explained by a number of factors: differences in the ventilator modes and settings employed; different levels of PEEP administered; and the fact that those authors instructed examiners to listen for specific sounds related to airflow limitation, whereas we did not.

Crackles are likely generated by sudden opening and closing of airways.[25] Therefore, the examiners heard crackles whenever critical airway opening and closing pressures were reached. In cases of unstable lung parenchyma with time constant inequalities, some airways can be completely or partially open while others remain closed. If critical opening and closing pressures are not reached, there will be increases in peak inspiratory pressure and in the dissipation of pressure against the viscoelastic components of the respiratory system, whereas C_{st},rs will probably decrease. In that situation, neither inspiratory nor expiratory crackles will be heard because the closed airways will remain closed and air will flow only through the open airways. In addition, whenever the critical opening pressure of a closed airway is reached, the pressure propagates deeper into the respiratory tree and the subsequent airway will open if its critical opening pressure is reached. This phenomenon leads to an avalanche of airway openings involving a large number of alveolar units. Because that process will increase the lung volume, the pressure will decrease.[26] Consequently, there will be tidal recruitment, which can lead to overestimation of the C_{st},rs. That might explain, at least in part, the lack of an association between crackles and low C_{st},rs in the present study. We should also consider that by applying a PEEP of 8 cmH_2O, we could have, at least to some degree, increased C_{st},rs and stabilized the lung parenchyma in some patients. Nevertheless, given that the PEEP was not titrated but was applied as a protocol, mechanical abnormalities in the lung periphery were still present in the majority of the patients evaluated.

In the present study, we found fair interobserver agreement in the evaluation of airway-related sounds and no interobserver agreement regarding sounds related to the lung parenchyma or chest wall. These results are in accordance with those reported in infants and adults during spontaneous breathing.[27,28] In another study of individuals evaluated during spontaneous breathing, Sapiteri et al.[29] demonstrated moderate interobserver agreement for wheezing, reduced breath sounds, and crackles, although the authors did not provide the 95% confidence interval values for the kappa statistics.

Many factors can influence the characteristics of breath sounds in mechanically ventilated patients (e.g., auscultation sites, subject positioning, body size, airflow waveform, and breathing pattern), thus modifying examiner perception of respiratory sounds. Because the two examiners in the present study performed chest auscultation under essentially the same conditions (same auscultation sites, same stethoscope, and same ventilator settings) and in rapid succession, we believe that the lack of agreement is inherent to the chest auscultation technique itself; low-to-moderate agreement in chest auscultation occurs even among the most experienced examiners.[30]

This study has some limitations. First, we evaluated patients only in the immediate postoperative period after cardiac surgery. Therefore, it would be interesting to assess the accuracy of chest auscultation in a population of individuals showing different degrees of mechanical abnormalities of the respiratory system. In addition, we did not analyze the subgroup of patients with respiratory disease prior to surgery separately, because they represented only a small proportion of our study sample. Furthermore, it is well known that the mechanical properties of the respiratory system, including the lungs and chest wall, are modified by the inspiratory flow rate, inspiratory time, and inspiratory volume.[31] Therefore, one could argue that such variables play a major role in determining the site at which respiratory sounds would be produced and therefore which type of sounds (airway-related sounds or sounds related to the lung parenchyma or chest wall) would be the predominant sounds that examiners hear. Because we did not modify the inspiratory time or the flow rate in order to evaluate chest auscultation accuracy under different inspiratory and expiratory conditions, as well as because chest auscultation can be partially modified by the manner in which mechanical ventilators are adjusted to deliver inspiratory volume, there is a need for further studies aimed at investigating the accuracy of chest auscultation in detecting abnormal respiratory mechanics with varying tidal volumes.

In summary, we found a dissociation between abnormal respiratory mechanics and respiratory sounds assessed with acoustic stethoscopes. Chest auscultation does not seem to be an accurate method for detecting abnormal respiratory mechanics in mechanically ventilated patients in the immediate postoperative period after cardiac surgery. Therefore, respiratory mechanics should be continuously monitoring at the bedside in mechanically ventilated patients. Although chest auscultation is still a mandatory component of a physical examination, breath sounds should be interpreted in conjunction with other respiratory parameters, such as the mechanical properties of the respiratory system.

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