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Ultrasonography in the Assessment of Lung Recruitment in Patients with Severe Pneumonia

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BACKGROUND Ultrasound study significantly expanded the possibilities of bedside diagnosis in patients with respiratory failure. Using ultrasound, it is possible to determine the volume of lung damage in the form of collapsed alveoli and infiltration areas with preserved airness of the lung tissue.
AIM OF STUDY To study the possibility of assessing the recruitment maneuver of the alveoli based on changes in the ultrasound signs of lung tissue damage.
MATERIAL AND METHODS A prospective study was performed in the Clinic of Anesthesiology and Resuscitation of S.M. Kirov Military Medical Academy. The study included 36 patients who were treated in the period from 2010 to 2017 with a duration of respiratory support of at least 48 hours and oxygenation index less than 300 mmHg. For 36 patients, 48 alveoli recruitment maneuvers were performed according to a step-by-step method under the control of dynamic compliance and average tidal volume. Ultrasound determined the type and extent of destruction of lung tissue by signs of infiltration and consolidation.
RESULTS In the studied patients, after carrying out a maneuver of recruitment of the alveoli, arterial blood oxygenation indices increased statistically significantly, $PaCO_2$ level decreased, pulmonary tissue compliance improved, respiratory volume grew. All this confirmed the mobilization of the alveoli and improved lung ventilation. Ultrasonographic evaluation of lung tissue showed a significant decrease in the severity of the ultrasound sign of infiltration after recruitment maneuver from 46.5 (38; 57.5) to 37.5 (30.5; 49.5). However, recruitment had practically no effect on the volume of the consolidated area of lung tissue: the general consolidation index before (4 (3; 5)) and after (4 (3; 5)) the maneuver had no statistically significant differences.
CONCLUSIONS The pneumonia-affected consolidated lung tissue has a low recruitment potential and the volume of consolidation does not change with the growth of PEEP. After the recruitment maneuver, the number of B-lines decreases, indicating a decrease in infiltration and an increase in lung airness.
Keywords: recruitment maneuver, ultrasound of the lungs, PEEP, consolidation, infiltration, pneumonia, respiratory failure, ventilatory support
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ALV – artificial lung ventilation
OI – oxygenation index
PEEP – positive end expiratory pressure

INTRODUCTION

Today, respiratory support occupies a leading place in the complex of intensive care for respiratory failure [1, 2]. The more severe the damage to the lungs, the more aggressive respiratory support parameters have to be used. The modern concept of artificial lung ventilation (ALV), "open lungs", implements a high level of positive pressure at the end of expiration (PEEP) and small tidal volumes, allowing to maximize gas exchange. "Protective ventilation" combines a small tidal volume, lower than the level of peak

pressure than with “open lungs”, and a selected optimal value of PEEP [2, 3]. Both of these concepts were developed to prevent the collapse of the affected and the opening of collapsed alveoli [3–5]. However, the principle of “open lungs” and protective ventilation due to a number of factors, including the “monotony” of mechanical ventilation, lead to an inhomogeneous state of lung tissue: the collapsed alveoli are located near the ventilated ones, and the number of potentially recruited alveoli remains quite large [6]. The most widely used method of mobilization of collapsed alveoli is the maneuver of “lung opening” (recruitment) [7]. Recruiting alveoli can significantly increase the number of functioning alveoli, lung compliance, oxygenation index and reduce the shunt fraction [8]. Currently, such methods of mobilization of the alveoli are known as: 40x40 technique, a step-by-step technique, an artificial sigh, a slow maneuver of recruitment of the alveoli, mechanical ventilation in the prone-position [9, 10].

The effect of the maneuver of mobilization of the alveoli is assessed indirectly using indicators of gas exchange and biomechanics of respiration, since they are the ultimate goal of recruitment. However , it is difficult to determine how much it was possible to mobilize collapsed and compressed alveoli directly at the patient’s bed, because traditional methods of examining the lungs are associated with radiation exposure, and the information content of such a method as chest X-ray in a patient in a supine position is not high. The ultrasound has become a new direction in visualizing the state of lung tissue and assessing the maneuver of recruitment of alveoli [11, 12]. While using ultrasound, it is possible to determine the volume of consolidated lung tissue with collapsed alveoli, areas of infiltration with preservation of airiness of lung tissue and areas with normal airiness without signs of damage [12, 13].

Aim of study: to analyze the possibility of ultrasound monitoring in assessing the recruitment maneuver of the lung alveoli.

MATERIAL AND METHODS

The prospective study was performed in the Clinic of Anesthesiology and Critical Care Medicine of S.M. Kirov Military Medical Academy. The study included 36 patients who were treated from 2012 to 2018.

The criteria for inclusion in the study were: age of patients - 18–75 years; the development of nosocomial and community-acquired pneumonia; duration of hardware respiratory support at least 48 hours; oxygenation index (OI) less than 300 mm Hg; recruitment maneuver .

Exclusion criteria: the presence of pneumothorax; chest trauma; the presence of a specific background disease (tuberculosis, sarcoidosis); lung surgery.

All patients were men, the average age was 31.5 (24; 42). Community-acquired pneumonia was observed in 25 patients, nosocomial pneumonia was observed in 11 patients. Thirty-six patients were underwent 48 maneuvers of recruitment of alveoli with staged procedure under the monitoring of the dynamic compliance and average tidal volume. The maneuver was performed with complete relaxation and sedation of the patient. After recruitment, *PEEP* was set 2-3 cm water column above the pressure of alveolar closure.

Ultrasound examination of the lungs, analysis of PaO_2, $PaCO_2$, OI (PaO_2/FiO_2), tidal volume (Vt), compliance (C) was performed immediately before initiation of the lung recruitment maneuver and 30 minutes after the end of the maneuver.

Ultrasound evaluation of lung tissue during the maneuver of recruitment of the alveoli was carried out according to a modified method of *Z. Jambrick*, 2004 [14]. The patient in a supine position was scanned with the portable ultrasonic device *SonoSite Edge* with convex transducer (3-5 MHz) and 6-zone technique (Fig. 1).

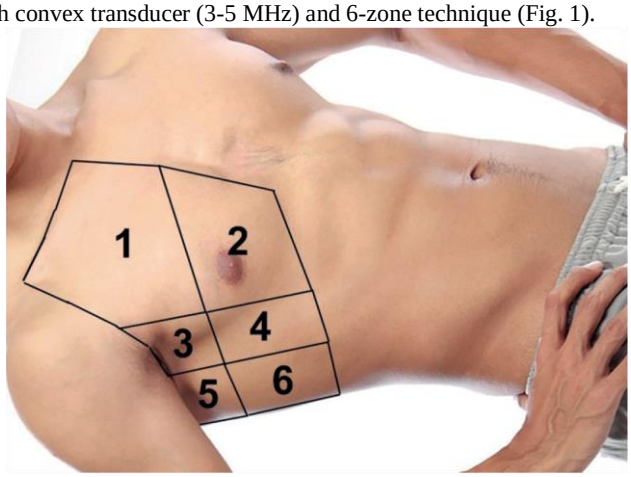

Fig. 1. Areas for untrosound. Numbers 1–6 indicate the scan area. By Z. Jambrick, 2004. [14]

During scanning, ultrasonic signs of lung tissue lesion were determined: infiltration and consolidation (Fig. 2).

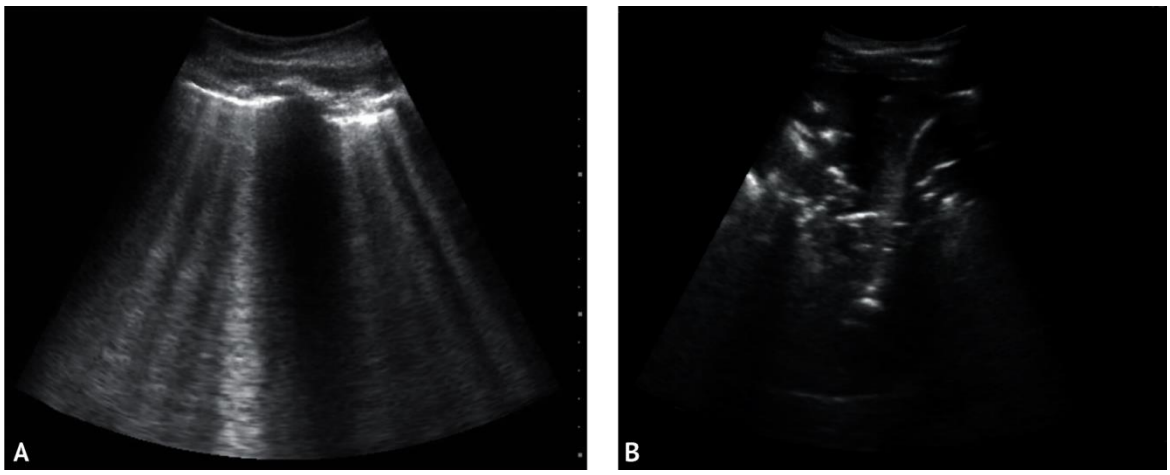

Fig. 2. Ultrasonic signs of lung tissue lesion. A is a sign of infiltration (B-line), B is a sign of consolidation (tissue sign)

In each scanning zone, the maximum number of B lines was recorded. The total index of B-lines was determined by summing the obtained values of B-lines in each zone. Tissue trait was recorded in each zone, indexing: 0 — no consolidation, 1 — part of the zone consolidated, 2 — entire zone consolidated. The total consolidation index was determined by summing the obtained values in all zones.

RESULTS

The traditional assessment of the effectiveness of a recruitment maneuver is an improvement in gas exchange and biomechanical properties of the lungs. In the examined patients, after carrying out a maneuver of recruitment of the alveoli, the arterial blood oxygenation parameters, OI increased statistically significantly, $PaCO_2$ level decreased, pulmonary tissue compliance improved, and tidal volume increased (p <0.00) (table).

The sonographic evaluation of lung tissue showed a significant decrease in infiltration after the recruitment maneuver. This is evidenced by a statistically significant decrease in the total index of B-lines. However, the recruitment had practically no effect on the volume of the consolidated zone of lung tissue: the general consolidation index before and after the maneuver had no statistically significant differences (p=0.2) (see table). The volume of consolidation did not change with an increase in *PEEP*, indicating a low recruitment potential of this tissue.

Table

Indicators of gas exchange, biomechanics of respiration, ultrasonic signs before and after the maneuver for alveoli recruitment

Parameter	Before recruitment	After recruitment	Wilcoxon test, Z, p
Total index of B-lines	46.5 (38; 57.5)	37.5 (30.5; 49.5)	-5.989 0.000
Total index of consolidation	4 (3; 5)	4 (3; 5)	-1.333 0.20
Tisal volume (Vt), ml	485 (425; 595)	570 (512.5; 702.5)	-3.520 0.000
PaO_2, mm Hg	84 (76.25; 89.25)	97.5 (89.75; 112.25)	-3.521 0.000
$PaCO_2$, mm Hg	43.05 (37.25; 47.98)	37.4 (34.18; 42.0)	-3.518 0.000
Oxygenation index (PaO_2/FiO_2)	42.5 (35.08; 53.03)	233 (196.65; 268.5)	-3.464 0.001
Compliance (C) ml/cm water column	29.65 (23.25; 42.25)	42.5 (35.08; 53.03)	-2.380 0.017

DISCUSSION

Evaluation of the effectiveness of lung recruitment maneuvers, as a rule, is carried out to improve indicators of gas exchange and biomechanical indicators of the lungs. This indicates that the recruitment maneuver led to the mobilization of alveoli, previously shut off from gas exchange. According to studies by *B. Lachmann* (1992), with a "complete opening" of the alveoli, the level of PaO_2 can exceed 450 mm Hg with inhalation of 100% oxygen [15].

Ultrasound provides new possibilities for bedside lung examination. The areas of consolidation visualized by ultrasound as a tissue sign indicate the absence of ventilation of the alveoli in this zone [13]. In our study, with an increase in *PEEP*, the volume of consolidation did not significantly change, which indicates a low recruitment potential of this tissue. Similar data on the poor recruibility of consolidated tissue were revealed by A.I. Yaroshetsky et al. (2017), which showed that an increase in *PEEP* did not lead to a significant decrease in consolidation volume during computed tomography of the lungs and an increase in the end-expiratory lung volume [6]. The departments of the lungs where the ultrasound infiltration sign was determined, on the contrary, showed a dynamics indicating a decrease in the amount of extravascular fluid in the interstitium of the lungs and an increase in

airiness during recruitment. The results obtained indicate that the improvement of ventilation occurred due to lung departments with an infiltration sign, and not due to consolidated areas. The data of our study are consistent with the results of other researchers who also revealed improved ventilation in the less affected sections of the lungs, and consolidated alveoli were not recruited [16, 17].

CONCLUSION

Ultrasound examination of the lungs makes it possible to assess changes in the lung tissue during the maneuver of recruitment of the alveoli. An increase in airiness during recruitment of the alveoli is determined by a decrease in the interstitial trait. Parts of the lungs, visualized by sonography as a consolidated sign, did not respond to recruitment.

FINDINGS

1. The pneumonia-affected consolidated pulmonary tissue has a low recruitment potential, and with increasing positive pressure at the end of exhalation, the volume of consolidation does not change.

2. After the recruitment maneuver, the number of B-lines decreases, indicating a decrease in infiltration and an increase in lung airiness.

REFERENCES

1. Vlasenko AV, Ostapchenko DA, Shestakov DA, Vodneva MM, Voyevodina YS, Neznamova NG, et al. Efficiency of Use of the "Lung Opening" Maneuver Under Artificial Ventilation in Patients With Acute Respiratory Distress Syndrome. *General Reanimatology*. 2002;4(6):50–59 (In Russ.).
2. Gel'fand BR.(ed.) *Nozokomial'naya pnevmoniya u vzroslykh.* 2nd ed., rev. and exp. Moscow: Meditsinskoe informatsionnoe agentstvo Publ.; 2016. (In Russ.)
3. Seal K., Featherstone R. *Airway Pressure Release Ventilation for Acute Respiratory Distress Syndrome: Clinical Effectiveness and Guidelines*. Ottawa (ON): Canadian Agency for Drugs and Technologies in Health; 2018 Feb. Available at: https://www.ncbi.nlm.nih.gov/books/NBK531787/pdf/Bookshelf_NBK531787.pdf [Accessed Oct 22, 2019] PMID: 30307725
4. Spieth PM, Güldner A, Carvalho AR, Kasper M, Pelosi P, Uhlig S, et al. Open lung approach vs acute respiratory distress syndrome network ventilation in experimental acute lung injury. *Br J Anaesth*. 2011;107(3):388–397. htpp://doi.org/10.1093/bja/aer257
5. Matthay MA, Zemans RL, Zimmerman GA, Arabi YM, Beitler JR, Mercat A, et al. Acute respiratory distress syndrome. *Nat Rev Dis Primers*. 2019;5(1):18. htpp://doi.org/10.1038/s41572-019-0069-0
6. Yaroshetskiy AI, Protsenko DN, Boytsov PV, Chentsov VB, Nistratov SL, Kudryakov ON, et al. Optimum level of positive end-expiratory pressure in acute respiratory distress syndrome caused by influenza A(H1N1)pdm09: balance between maximal end-expiratory volume and minimal alveolar overdistension. *Russian Journal of Anaesthesiology and Reanimatology*. 2016;(6):425–432. http://doi.org/10.18821/0201-7563-2016-61-6-425-432
7. Goligher EC, Hodgson CL, Adhikari NKJ, Meade MO, Wunsch H, Uleryk E, et al. Lung Recruitment Maneuvers for Adult Patients with Acute Respiratory Distress Syndrome. A Systematic Review and Meta-Analysis. *Ann Am Thorac Soc.* 2017;14(Supplement 4):304–311. PMID: 29043837 http://doi.org/10.1513/AnnalsATS.201704-340OT
8. Nguyen A. Use of Recruitment Maneuvers in Patients With Acute Respiratory Distress Syndrome. *Dimens Crit Care Nurs*. 2018;37(3):135–143. PMID: 29596290 http://doi.org/10.1097/DCC.0000000000000298
9. Tusman G, Acosta CM, Costantini M. Ultrasonography for the assessment of lung recruitment maneuvers. *Crit Ultrasound J*. 2016;8(1):8. PMID: 27496127 http://doi.org/10.1186/s13089-016-0045-9
10. Bhattacharjee S, Soni KD, Maitra S. Recruitment maneuver does not provide any mortality benefit over lung protective strategy ventilation in adult patients with acute respiratory distress syndrome: a meta-analysis and systematic review of the randomized controlled trials. *J Intensive Care*. 2018;6:35. PMID: 29983985 http://doi.org/10.1186/s40560-018-0305-9
11. Godet T, Constantin JM, Jaber S, Futier E. How to monitor a recruitment maneuver at the bedside. *Curr Opin Crit. Care*. 2015;21(3):253–258. PMID: 25827586 http://doi.org/10.1097/MCC.0000000000000195
12. Radzina M, Biederer J. Ultrasonography of the Lung. RöFo – Fortschritte auf dem Gebiet der Röntgenstrahlen und der bildgeb Verfahren. *Rofo*. 2019;191(10):909–923. PMID: 30947352 http://doi.org/ 10.1055/a-0881-3179
13. Volpicelli G, Elbarbary M, Blaivas M, Lichtenstein DA, Mathis G, Kirkpatrick AW, et al. International evidence-based recommendations for point-of-care lung ultrasound. *Int Care Med*. 2012;38(4):577–591. http://doi.org/10.1007/s00134-012-2513-4
14. Jambrik Z, Monti S, Coppola V, Agricola E, Mottola G, Miniati M, et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. *Am J Cardiol*. 2004;93(10): 1265–1270. PMID: 15135701 http://doi.org/10.1016/j.amjcard.2004.02.012
15. Lachmann B. Intensive Care Medicine Editorial Open up the lung and keep the lung open. *Int Care Med*. 1992;18(6):319–321. PMID: 1469157 http://doi.org/10.1007/bf01694358
16. Gattinoni L, Pelosi P, Suter PM, Pedoto A, Vercesi P, Lissoni A. Acute Respiratory Distress Syndrome Caused by Pulmonary and Extrapulmonary Disease Different Syndromes? *Am J Respir Crit Care Med.* 1996;158(1):3–11. PMID: 9655699 http://doi.org/10.1164/ajrccm.158.1.9708031
17. Marchenkov YuV, Moroz VV, Izmailov VV. Pathophysiology of Recruit Ventilation and its Impact on the Breath Biomechanics (review). *Russian Journal of Anaesthesiology and Reanimatology*. 2012;(3):34–41. (In Russ.)

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