Pulmonary Aeration and Posterior Collapse Assessed by Electrical Impedance Tomography in Healthy Children: Contribution of Anesthesia and Controlled Mechanical Ventilation

To the Editor:

Anesthesia is associated with the development of atelectasis, which may affect lung ventilation. These changes persist into the postoperative period and are associated with postoperative respiratory complications.[1] Electrical impedance tomography has been used in the operating room to monitor changes in aeration and to guide intraoperative ventilatory settings in a strategy to prevent atelectasis.[2] The end-expiratory lung impedance tracks changes in lung aeration, and its correlation with functional residual capacity has been previously validated.[3]

The aim of this study was to evaluate the changes in the lung aeration estimated by electrical impedance tomography as the end-expiratory lung impedance after anesthesia induction in pediatric patients. This was a prospective, single-center, observational study including healthy children younger than 5 yr who underwent nonthoracic surgery. Monitoring was performed continuously before and throughout the surgical period. Data analysis was divided into five periods: induction–spontaneous breathing, ventilation–5 min (initial 5 min of controlled ventilation), ventilation–30 min, ventilation–late (final 5 min of controlled ventilation), and recovery–spontaneous breathing (after removal of the artificial airway and restoration of spontaneous breathing). End-expiratory lung impedance was analyzed cycle by cycle in these five periods.

A total of 20 pediatric patients undergoing nonthoracic surgery with general anesthesia were included. Their mean age was 27.5 months and 90% were male. Postectomy was the most frequent surgery (n = 16), followed by hernioplasty

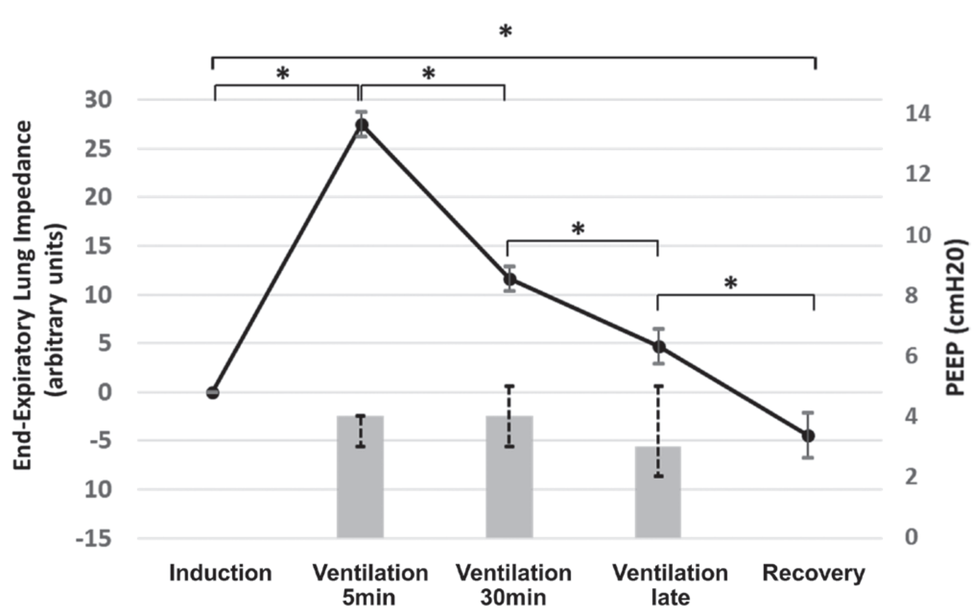

Fig. 1. Global end-expiratory lung impedance (*black line*, left vertical axis) and positive end-expiratory pressure (PEEP; *gray bars*, right vertical axis) in the five different periods studied. Note that no PEEP was used in the pre– and post–mechanical ventilation periods. Statistically significant variations were observed in the end-expiratory lung impedance measurements in all comparisons ($P < 0.001$). There was no difference in PEEP values during mechanical ventilation. As usual for this technique, electrical impedance tomography was measured in arbitrary units. The different periods were compared using mixed linear models. The results presented correspond to point estimates and 95% CI of the model.

(n = 8) and cholecystectomy (n = 1), while five patients underwent two associated procedures. Ventilatory parameters were stable during the three controlled mechanical ventilation moments analyzed, with a mean positive end-expiratory pressure (PEEP) of 4 cm H_2O (fig. 1).

There was an initial increase in the global aeration (measured with the end-expiratory lung impedance; fig. 1) when mechanical ventilation was initiated (difference, 27.52 [95% CI, 26.27 to 28.77]; $P < 0.001$), and a subsequent progressive decrease during the time that patients were under general anesthesia (difference, −15.88 [95% CI, −17.42 to −14.34]; $P < 0.001$). After spontaneous breathing resumption, during recovery, the dependent posterior region presented aeration loss in comparison with the induction period, depicted by the lower end-expiratory lung impedance values found by electrical impedance tomography (difference, −7.46 [95% CI, −8.78 to −6.14]; $P < 0.001$). In opposition to this finding, there was a rise in the anterior nondependent, end-expiratory lung impedance when comparing induction with recovery periods (difference, 4.96 [95% CI, 3.9 to 6.52]; $P < 0.001$; fig. 2).

Some authors have studied the negative impact of anesthesia on children's functional residual capacity,[4,5] and this has encouraged a debate around the importance of using enough PEEP to prevent atelectasis also in this age group.[4,6] During general anesthesia in the adult population, PEEP values can vary depending on patients' characteristics and on the surgical intervention proposed. As a result, the use of a one-size-fits-all PEEP seems inappropriate, even for patients with healthy lungs.[7,8]

We monitored the entire surgical time since the start of mechanical ventilation until the restoration of spontaneous breathing in the recovery period. This made it possible to evaluate the temporal trend of lung aeration during controlled mechanical ventilation. With PEEP values of 3 to 4 cm H_2O, we found a progressive decrease in the end-expiratory lung impedance in the posterior lung regions, which suggests that these pressures were insufficient to maintain the lung aeration over time. This concept was previously demonstrated in children under general anesthesia, where a PEEP of 3 cm H_2O was not enough to prevent aeration loss, but a PEEP of 6 cm H_2O kept aeration stable even under high inspired oxygen fractions.[9] Other authors found that a PEEP of 5 cm H_2O after a recruitment maneuver avoided lung collapse in children under general anesthesia for laparoscopy. These authors suggested that PEEP choice should be individualized, given the impact of individual and surgical factors over the risk of atelectasis.[10]

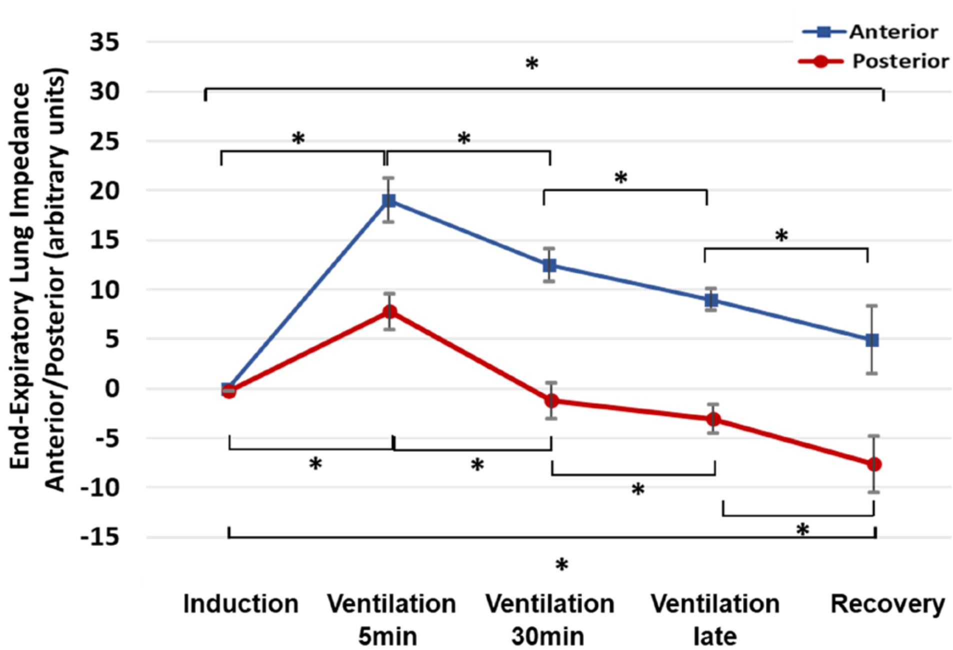

Fig. 2. Anterior (*blue line*) and posterior (*red line*) end-expiratory lung impedance measurements presented during the five periods studied. Statistically significant variations were observed in the end-expiratory lung impedance measurements in all regions in all comparisons ($P < 0.001$). After the restoration of spontaneous breathing (Recovery-Spontaneous Breathing), the posterior region showed lower end-expiratory lung impedance values than the induction moment, suggesting the loss of functional residual capacity in this region. Otherwise, the anterior nondependent region presented an end-expiratory lung impedance value at the Recovery-Spontaneous Breathing significantly higher than the Induction-Spontaneous Breathing moment. As usual for this technique, electrical impedance tomography was measured in arbitrary units. Anterior and posterior end-expiratory lung impedance values were compared among the evaluation times using mixed linear models. Results are presented as least squares means with SD.

Our study has several limitations. First, it was an observational, descriptive study, and as such we cannot draw any conclusions about the causal influence of the variables studied on the outcome. Second, because of the small sample size, we could not study relevant subgroups such as age categories, use of neuromuscular blockers (in two patients), use of laryngeal masks *versus* tracheal tubes. Third, this was a single-center study, and the results reflect the local practice.

In conclusion, we demonstrated that aeration decreased progressively especially in the dorsal lung regions during controlled mechanical ventilation. This finding supports the hypothesis of progressive atelectasis formation predominantly in dorsal regions. Future studies should test whether different ventilatory settings, such as higher PEEP values, can prevent this atelectasis formation and even prevent postoperative complications in children.

Regulatory Approval

This study was submitted to the Ethics and Research Committee of Israelita Albert Einstein Hospital, CAAE 89911218.6.0000.0071, and to the Ethics and Research Committee of the School of Medicine of the University of São Paulo, CAAE 89911218.6.3001.0065.

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Competing Interests

Dr. Costa has the following financial relationships: consulting fees from Magnamed SA (São Paulo, Brazil) and consultant for Timpel S.A. (São Paulo, Brazil). Dr. Rossi is consultant for Timpel S.A and Marcelo B. Dr. Amato is a minority shareholder of Timpel S.A., and his research laboratory has received grants in the past 5 yr from the Covidien/Medtronics (São Paulo, Brazil; mechanical ventilation), Orange Med/Nihon Koden (São Paulo, Brazil; mechanical ventilation) and Timpel S.A (São Paulo, Brazil; electrical impedance tomography). The other authors declare no competing interests.

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REFERENCES

1. Hedenstierna G: Alveolar collapse and closure of airways: regular effects of anaesthesia. Clin Physiol Funct Imaging 2003; 23:123–9
2. Bauer M, Opitz A, Filser J, Jansen H, Meffert RH, Germer CT, Roewer N, Muellenbach RM, Kredel M: Perioperative redistribution of regional ventilation and pulmonary function: A prospective observational study in two cohorts of patients at risk for postoperative pulmonary complications. BMC Anesthesiol 2019; 19:132
3. Mauri T, Eronia N, Turrini C, Battistini M, Grasselli G, Rona R, Volta CA, Bellani G, Pesenti A: Bedside assessment of the effects of positive end-expiratory pressure on lung inflation and recruitment by the helium dilution technique and electrical impedance tomography. Intensive Care Med 2016; 42:1576–87
4. Riva T, Pascolo F, Huber M, Theiler L, Greif R, Disma N, Fuchs A, Berger-Estilita J, Riedel T: Evaluation of atelectasis using electrical impedance tomography during procedural deep sedation for MRI in small children: A prospective observational trial. J Clin Anesth 2022; 77:110626
5. Humphreys S, Pham TM, Stocker C, Schibler A: The effect of induction of anesthesia and intubation on end-expiratory lung level and regional ventilation distribution in cardiac children. Paediatr Anaesth 2011; 21:887–93
6. Heath C, Hauser N: Is there a role for lung-protective ventilation in healthy children? Paediatr Anaesth 2022; 32:278–85
7. Pereira SM, Tucci MR, Morais CCA, Simões CM, Tonelotto BFF, Pompeo MS, Kay FU, Pelosi P, Vieira JE, Amato MBP: Individual positive end-expiratory pressure settings optimize intraoperative mechanical ventilation and reduce postoperative atelectasis. Anesthesiology 2018; 129:1070–81
8. Futier E, Constantin JM, Paugam-Burtz C, Pascal J, Eurin M, Neuschwander A, Marret E, Beaussier M, Gutton C, Lefrant JY, Allaouchiche B, Verzilli D, Leone M, De Jong A, Bazin JE, Pereira B, Jaber S; IMPROVE Study Group: A trial of intraoperative low-tidal-volume ventilation in abdominal surgery. N Engl J Med 2013; 369:428–37
9. von Ungern-Sternberg BS, Regli A, Schibler A, Hammer J, Frei FJ, Erb TO: The impact of positive end-expiratory pressure on functional residual capacity and ventilation homogeneity impairment in anesthetized children exposed to high levels of inspired oxygen. Anesth Analg 2007; 104:1364–8, table of contents
10. Acosta CM, Sara T, Carpinella M, Volpicelli G, Ricci L, Poliotto S, Abrego D, Gonorazky S, Böhm SH, Tusman G: Lung recruitment prevents collapse during laparoscopy in children: A randomised controlled trial. Eur J Anaesthesiol 2018; 35:573–80

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