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A modified version of ultrasonography was used to evaluate and track the effects of positive end-expiratory pressure-induced lung deaeration in infants undergoing general anaesthesia for congenital heart disease.

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Abstract:

A reliable approach to diagnosing pulmonary atelectasis is the use of lung ultrasonography. This research was conducted to identify the most effective location for monitoring atelectasis changes in children with general anaesthesia to treat congenital heart disease. **Methodology:** Prospective study. **Place:** This is the CTVS Department of SCB Medical College in Cuttack. **Subjects:** Children who are having elective general anaesthesia for treatments linked to congenital cardiac conditions between the ages of three months and three years. **A course of action:** A control group that received standard treatment and a group that was randomly allocated to receive 4 cm H2O positive end-expiratory pressure were both given to thirty children who were diagnosed with congenital heart disease. Sonography of the lungs was performed on each patient twice during the first and second rounds of mechanical breathing before the surgical procedure.

A comparison was made between the two examinations in terms of the atelectatic regions and B-lines. Bland-Altman plots were used to evaluate the different ultrasound locations. The inferno-posterior (Scans 4-6) areas of the lungs were demonstrated to have a greater incidence of atelectasis in contrast to the anterior and lateral (Scans 1-3) regions. The group receiving positive end-expiratory pressure had lower values (7.6-8.7) ($p < 0.05$) on lung ultrasonography, while the therapy group had higher median (interquartile range) scores (7.6-16.6). The control group's values were higher when compared. The atelectatic region significantly decreased in the group treated with positive end-expiratory pressure. The atelectatic area fell from 126 mm2 (33.5-214.4 mm2) to 48.4 mm2 (4.9-73.2 mm2), with a p-value of less than 0.05. Following the Bland-Altman plots, the measures obtained from Scans 1-6 and 4-6 agreed. The group exposed to positive end-expiratory pressure had significantly more significant alterations in the atelectatic area in the posterior axillary line areas compared to the group not exposed to this pressure ($p = 0.02$, 0.003 and 0.02, respectively). **Conclusion:** Although it may not entirely eradicate the problem, a positive end-expiratory pressure of 4 cm H2O may help reaerate the lungs and alleviate the severity of atelectasis in infants with congenital heart disease. To reduce time during the examination, a lung ultrasound may be done instead of a CT scan of the lower and upper lungs, which may reveal additional signs of atelectasis.

Keywords: Congenital heart disease, lung ultrasound, positive end-expiratory, atelectasis, Bland-Altman plots.

Introduction:

One of the most prevalent side effects of general anaesthesia in children is atelectasis [1]. It impacts 68% to 100% of kids who have their airway cleared by tracheal intubation or a laryngeal mask. From a partial to a complete collapse of the lungs, the degree of atelectasis might vary depending on the disease, the kind of operation, and the anesthetic medication utilized [1-4]. Apart from raising the probability of lung inflammation, atelectasis may also make it challenging to exchange gases and perform mechanical ventilation [2].

Most instances of anaesthesia-induced atelectasis disappear on their own in children who are having minor surgery and have a heart and lungs that are typically healthy [5-8]. Despite this, atelectasis is nevertheless rather prevalent in children who have had cardiac surgery, with rates of 41%, 57%, and 71% in the first three days after the procedure [3]. This high prevalence of postoperative atelectasis in children with cardiac illness is attributable, in part, to cardiac abnormalities, which affect lung physiology, and, in part, to surgical compression and cardiopulmonary bypass. Both of these factors contribute to the risk of developing asthma. A further potential fundamental impact is the ventilation control that is not appropriately done [4]. Pulse oximetry, end-tidal CO2 pressure, intermittent blood gas analysis, and lung mechanics are the main factors that control the ventilator when the patient is under general anaesthesia. This is in contrast to the traditional method of directly measuring and monitoring lung aeration [5].

Even though computed tomography (CT) and other imaging modalities can accurately assess lung aeration [6], it is not feasible to utilize them in operating rooms. Additional downsides include the exposure to radiation and the time necessary for these treatments [7-11].

In ultrasonography, pulmonary illnesses such as pneumothorax, atelectasis, and pulmonary oedema have lately been recognized as diagnostic techniques that do not need radiation [8]. Ultrasound can deliver a more accurate diagnosis compared to CT and chest radiography [9]. In addition, it can monitor changes in lung aeration in real-time by using direct recruitment techniques [10]. Many other methods have been employed in evaluating atelectasis, such as the 12- and 4-sector techniques [4,11]. When children are under general anaesthesia, the distribution of atelectasis may vary, and this is especially true for children who have congenital heart diseases (CHD) [12]. The optimal location to examine the atelectasis changes in children having cardiac surgery has not yet been determined, and there is no apparent agreement.

Our primary goal in this study was to determine the best way to use ultrasonography to track the development of atelectasis in children undergoing heart surgery under general anaesthesia. We also looked at how low positive end-expiratory pressure (PEEP) affects breathing air and pressure-controlled ventilation.

Materials & methods:

Now that the Institutional Ethics Committee has approved, the investigation into the matter may begin. The CTVS Department at SCB Medical College in Cuttack was the site of this prospective trial, which ran from September 2017 to September 2018. The study was placed at Cuttack. Patients undergoing elective general anaesthesia for the treatment of congenital heart disease include children aged three months to three years old. **A course of action:** A control group that received standard treatment and a group that was randomly allocated to receive 4 cm H2O positive end-expiratory pressure were both given to thirty children who were diagnosed with congenital heart disease. Who is eligible: Between September 2017 and December 2017, screening for congenital heart disease that was not a medical need was performed on every patient. Before undergoing the treatment, all patients eligible for anaesthesia were provided with signed informed consent papers issued by their legal guardians. Under general anaesthesia, children who were no more than three months old and who matched the inclusion criteria were scheduled to have elective coronary heart surgery over the course of the study. A recent respiratory tract infection, emergency surgery, a history of thoracic or cardiac surgery, a history of pulmonary disease, a genetic disorder, abnormal findings on a chest radiograph or CT before surgery (such as atelectasis, pneumothorax, pleural effusion, or pneumonia), and vasoactive support administered before anaesthesia were the criteria that were used to exclude applicants from the study.

Using a random number table, the patients were randomized to one of two groups: one group was given PEEP. In contrast, the other group was assigned control. Immediately after intubation, the PEEP group was administered 5 cm H2O PEEP. In comparison, the control group was given 0 cm H2O PEEP. The individuals who participated in the study and the anesthetists who reviewed the data were uninformed of the treatments they had received. Twenty to thirty minutes before being taken into the operating room, each patient received an oral dosage of midazolam at a rate of 0.5 mg/kg.

A combination of intravenous preoxygenation with 100% oxygen, 0.05-0.1 mg/kg of midazolam, 0.2-0.3 mg/kg of etomidate, 0.3-1.5 mg/kg of fentanyl, and 0.6-0.9 mg/kg of rocuronium were administered to induce anaesthesia. Aside from using 40% oxygen and air to maintain anaesthesia, intravenous infusions of fentanyl (0.3 to 1.5 mg per kg per hour), rocuronium (0.6 mg per kg per hour), and propofol (4.0 to 6.0 mg per kg per hour) were also administered. A cuff-equipped endotracheal tube of an appropriate size was used to enable pressure-controlled breathing. A satisfactory inspiratory-expiratory ratio of 1:2 was achieved by modifying the ventilator to breathe between 16 and 30 times per minute. This measure was carried out since the patient's age was considered. The inspiratory pressure was adjusted to maintain a tidal volume of 8.0-10 mL/kg and an end-tidal carbon dioxide concentration of 35-45 mm Hg, making this possible. Rectal and nasal temperatures, transesophageal echocardiography, noninvasive blood pressure, invasive arterial blood pressure, electrocardiography, blood oxygen saturation, and noninvasive blood pressure were all part of the standard monitoring that occurred during the heart surgery procedure. A disposable blanket and a forced-air heating device were used to keep the body temperature regular. Everyone who participated in the study had lung ultrasonography done twice. The first inspection was conducted quickly after the end of the mechanical ventilation, followed by the second examination fifteen minutes later. The anesthesiologist performed the ultrasound treatments using a Vivid-i ultrasound machine with a linear transducer running at 12 MHz. He relied on his prior knowledge and completed over fifty pediatric lung ultrasound exams.

The patients were asked to lie on their backs with their arms extended above their heads so that they could be scanned. The individual under scrutiny had twelve scans, six carried out on each side of the chest. The catheter was found to be positioned in the midline of the clavicle in scans 1 and 2. The catheter was discovered to be inserted into the middle axillary catheter on the side in picture 3. Scans taken along the posterior axillary line (Scans 4-6) revealed intercostal gaps in three

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different places: five, six, and seven. We thoroughly examined all twelve distinct lung regions in just over two minutes, going from top to bottom and right to left for each. The "sliding" sign, A-lines, B-lines, atelectasis, and air bronchograms are only a few lung abnormalities that may be measured and recorded using ultrasonography.

In a research that was conducted by [4], an assessment process was presented that classified lung aeration using a scale that ranged from 0 to 3. 0 indicated that there were no lines or fewer than two isolated B-lines, one stated that there were well-defined B-lines, 2 indicated that there were numerous coalescent B-lines, and three indicated that the lungs had consolidated. The values obtained from a representative ultrasound were used to measure atelectatic zones. We conducted our measurements and evaluations to determine the amount of lung aeration in each region. The frequency with which hemodynamic instability occurred was also noted during the PEEP recruitment. Sixty-eight to one hundred per cent of neonates who have general anaesthesia will develop atelectasis [2,3]. As a result, we hypothesized that the rate of atelectasis would be 85 per cent and that the rate would be reduced to 44 per cent by using PEEP.

Statistical analysis:

The Shapiro-Wilk test was used to check whether the distribution under consideration was normal. For this purpose, we compared the groups using either the Student's t-test or the Mann-Whitney U test. Assuming normally distributed data was a prerequisite for selecting an appropriate test. We used Fisher's exact test to analyze the categorical variables. Using the Mann-Whitney U test, we compared the different organizations' ultrasonography results, atelectatic regions, and changes in atelectatic areas. To further comprehend the findings of comparisons conducted within the same group, the Wilcoxon signed-rank test was used to compare the ultrasonography scores, atelectatic regions, and occurrences of atelectasis. To examine the relationship between the two variables, we computed the Spearman's correlation coefficient. The level of agreement between the two separate ultrasound slices was analyzed using a Bland-Altman plot. We employed a criteria of $P < 0.05$ to determine statistical significance.

Results:

Only 30 out of 49 youngsters diagnosed with coronary heart disease were deemed eligible for inclusion. There were no differences between the groups concerning the variables identified at the outset of the investigation (Tables). One minute after beginning artificial breathing, 11.6 per cent of the scanned children had region-specific atelectasis, and there was no significant difference in the incidence of occurrence between the groups. On the other hand, atelectasis was much more prevalent in Scans 4-6 compared to Scans 1-3, which was relatively rare. On Scans 4-6, patients who used a PEEP of 4 cm H2O for pressure-controlled mechanical breathing had much-reduced rates of atelectasis.

The following display the results of our further study on the impacts of mechanical ventilation using atelectatic area and PEEP lung aeration score. Lung aeration scores in Scans 4-6 and 1-6 were significantly reduced using pressure-controlled mechanical ventilation with PEEP. A score of 12 (8–14) was replaced with 8 (3.4–9.1) and a score of 9 (3.4–9.9). When PEEP was not used during pressure-controlled mechanical ventilation, neither the lung aeration score nor the atelectatic region was significantly affected. The atelectatic region shrank from 128 mm2 to 126 mm2 (33.5-214.4 mm2) and finally to 48.4 mm2 (4.9-73.2 mm2) due to this reason. Table 4 displays the results, which reveal that before treatment, the atelectatic regions of the left lung were much larger than the right lung in both the PEEP and control groups.

A Bland-Altman plot was also used to assess the changes across several ultrasonography regions. The results from Scans 1-6 and 4-6 were in perfect agreement, as shown by the Bland-Altman plot. Contrarily, Scans 1-3 disagreed with Scans 1-6. The figure shows how the atelectatic zones changed in the PEEP group compared to the control group. The scan sites used in this comparison are varied. The group that received PEEP saw significantly higher atelectatic area changes in Scans 4-6 compared to the group that served as the control ($p = 0.02$, 0.003, and < 0.04, and correspondingly).

Table 1: Atelectasis Incidence Rates Predicted by Pre- and Post-Treatment Lung Ultrasound

Variable	Positive End-Expiratory Pressure (PEEP) Group			Control Group		
	Before Treatment	After Treatment	P	Before Treatment	After Treatment	P *
Scan 1	3	0		0	0	
Scan 2	0	0		0	0	
Scan 3	3	0		4	2	
Scan 4	26	19	0.02	25	26	0.801
Scan 5	25	12	0.003	24	24	1.000
Scan 6	16	9	0.02	16	18	0.458

The age before treatment was shown to have a negative link with the severity of the atelectatic areas and the three-dimensional ultrasonography scores ($r = -0.53$, $p = 0.002$ and $r = -0.69$, $p < 0.05$, respectively). We had eight patients in the group that used bidirectional shunts and twenty in the group that used left-to-right shunts. A random assignment was made to each group. A report was sent to the other two patients without any specific classification. Thirty patients were found to have taken part in this study. There were no statistically significant differences between the two groups regarding the atelectatic areas and ultrasonography scores. None of the patients indicated hemodynamic instability or air leakage during the evaluation.

Table 2: Scores from Lung Ultrasounds of Study Participants

Variables	Positive End-Expiratory Pressure (PEEP) Group (n=15)	P^a	Control Group (n=15)	P^b	P^c
Pre-treatment, median (Interquartile range)					
Ultrasound Score	13 (8- 15.8)		13 (8 – 17.9)		0.893
Scan 1-3	0		0.6		0.569
Scan 4-6	14		10.8		0.479

After Treatment (Interquartile range)					
Ultrasound Score 9 (2.8 – 9.1)		0.0001	14	0.498	0.002
Scan 1-3	0	0.039	2	0.512	0.088
Scan 4-6	8	0.0001	13	0.198	0.003

a First vs second ultrasound examination in the positive end-expiratory pressure (PEEP) group.
b First vs second ultrasound examination in the control group.

c PEEP group vs control group.

Discussion:

Our examination of lung ultrasonography regions that assess atelectasis changes in newborns with CHD was carried out while the patients were under general anaesthesia. Compared to the anterior or lateral regions, the inferior-posterior areas experienced a much higher incidence of atelectasis. It is important to note that the selection of the ultrasonography section impacts both the evaluation of the use of PEEP and the identification of atelectasis. Furthermore, according to the findings of perioperative lung ultrasonography exams, a positive end-expiratory pressure of 4 cm H2O was beneficial in lowering atelectasis and reaerating the lungs.

Eighty-two point five per cent of the people who participated in this research were found to have atelectasis after just one minute of artificial breathing. Our study's results lend credence to previous studies' findings that show that atelectasis is caused in children during the process of inducing general anaesthesia [15,16]. There is a possibility that children with congestive heart failure may have atelectasis before the initiation of mechanical ventilation. The development of atherosclerosis occurs when the volume of the resting lungs and their functional residual capacity are decreased, which increases gas consumption and the closure of the airways [4]. The development of atelectasis may be managed by adjusting the oxygen concentration during preoxygenation and introducing anaesthesia [2,3]. During this research, it is probable that the quick development of atelectasis was brought on by using 100% oxygen for the preoxygenation process. In addition, before the administration of treatment, the left lung had more extensive atelectatic areas than the right lung. This discovery could be explained by the fact that children who have CHD are in danger of having their airways collapse. These children may have an enlarged heart. When trying to understand atelectasis better, it is recommended to scan other lung locations. Despite this, the monitoring of changes in atelectasis is made more difficult by the fact that additional scans are time-consuming to do. This is because there are significant differences in the distribution of atelectasis. The results that we got are consistent with those of kids who were given general anaesthesia [14].

Atelectasis may be caused by gravity events, especially in the inferior and posterior lung regions of scans 4-6. As demonstrated by Bland-Altman plots and Supplemental Digital Content 1 (http://links.lww.com/PCC/A876), there were no significant changes in atelectatic areas in the anterior and lateral regions, and measurements in Scans 1-6 and Scans 4-6 were concordant. Furthermore, there were no notable alterations in the general atelectatic domains. Our results suggest that inferno-posterior ultrasonography (Scans 4-6) may be able to lessen the time needed for examination while more accurately identifying changes in atelectasis compared to other sites.

It could be able to exclude Scans 1-3 from the investigation of how mechanical ventilation affects atelectasis because of the scans' low incidence of atelectasis. This is also the case since these scans were carried out.

Age-related atelectasis may manifest in patients of any age. Our study demonstrated a negative connection between age, preoperative ultrasonography scores and atelectasis in children [12]. This result is in line with the conclusions of other studies. Athetosis is more common in younger children than in older children because of differences in pulmonary physiology, including a more elastic chest wall and a more extraordinary ability for respiratory closure. Therefore, it is of the utmost importance to manage mechanical ventilation securely, and we would like to emphasize that PEEP is advantageous for youngsters. [10,11] Research has shown that PEEP may assist patients under general anaesthesia in avoiding postoperative lung difficulties and reducing or eliminating atelectasis.

On the other hand, there is a dearth of knowledge about the impact of PEEP on children who are routinely anaesthetized and who have coronary heart disease. Our research showed that a 4 cm H2O PEEP may reduce atelectasis and enhance lung reaeration in children born with congenital cardiac abnormalities. This was demonstrated via the use of ultrasonography. On the other hand, the PEEP group continued to have atelectatic zones, although they were much reduced after the treatment. As a result, a PEEP of 4 cm H2O is probably not enough to eliminate atelectasis in babies. To prevent atelectasis, it is advised to do high-level PEEP or ultrasound-guided manual recruitment.

On the other hand, this recruitment procedure may result in unfavorable consequences, including hypotension, barotrauma, oxygen desaturation, and lung injury caused by the ventilator [12]. Furthermore, changes in hemodynamics may occur due to an increase in intrathoracic pressure brought about by high levels of PEEP [9]. In light of this, there is a need for more investigation into the therapeutic significance and effectiveness of atelectasis removal in children with congenital heart defects via recruitment procedures or high-level PEEP. There was not a single instance of hemodynamic instability among any of the youngsters evaluated for this research piece.

Conclusion:

The results of our research indicate that ultrasonography of the inferior-posterior regions of the lungs may save the amount of time required and increase the likelihood of detecting alterations in atelectatic zones. In children with congenital heart abnormalities, a 4 cm H2O PEEP guided by ultrasonography offers an additional option for reaerating the lungs and lowering (but not eradicating) atelectasis while reducing the severity of the condition. These findings need to be investigated further using large-scale randomized and anonymous studies.

Conflict of interest:

The authors have no conflicts of interest to declare.

References:

1. Abdel-Ghaffar HS, Abdelaal HM, Abdelkareem MA, Hassanein SM, Abbas YH. Lung ultrasound imaging and clinical consequences of intraoperative high inspired oxygen fraction in healthy mechanically ventilated children. Trends in Anaesthesia and Critical Care. 2023 Dec 22:101326.
2. Gao Q, Ji H, Wu Z, Zhao P. Effect of ultrasound-guided lung recruitment manoeuvre on perioperative atelectasis during laparoscopy in young infants: A randomized controlled trial. Journal of clinical anaesthesia. 2023 Jun 1;86:111075.
3. Hepworth-Warren KL, Nelson NC, Dembek KA, Young KA. General anaesthesia does not induce ultrasonographic changes in the pleura of healthy adult horses anaesthetized for elective magnetic resonance imaging. Journal of the American Veterinary Medical Association. 2023 Apr 1;261(4):500-4.
4. Haddam M, Zieleskiewicz L, Perbet S, Baldovini A, Guervilly C, Arbelot C, Noel A, Vigne C, Hammad E, Antonini F, Lehingue S. Lung ultrasonography for assessment of oxygenation response to prone position ventilation in ARDS. Intensive care medicine. 2016 Oct;42:1546-56.
5. Hepworth-Warren KL, Nelson NC, Dembek KA, Young KA. General anaesthesia does not induce ultrasonographic changes in the pleura of healthy adult horses anaesthetized for elective magnetic resonance imaging. Journal of the American Veterinary Medical Association. 2023 Apr 1;261(4):500-4.
6. Nair PR, Ramachandran R, Trikha A, Anand RK, Rewari V. Effect of positive end-expiratory pressure on atelectasis in patients undergoing major upper abdominal surgery under general anaesthesia: A lung ultrasonography study. Journal of Perioperative Practice. 2023 Apr;33(4):99-106.
7. Farrell C, Cooper K, Hayward S, Walker C. Exploring the Use of Lung Ultrasonography to Assess Cardiac Surgery Patients: A Scoping Review. Journal of Diagnostic Medical Sonography. 2023 Sep 22:87564793231198521.
8. Schwarz S. Pulmonary Sonography–Neonatal Diagnosis Part 2. Ultraschall in der Medizin-European Journal of Ultrasound. 2023 Jan 20.
9. Cressoni M, Chiurazzi C, Chiumello D, Gattinoni L. Does high PEEP prevent alveolar cycling? Medizinische Klinik, Intensivmedizin und Notfallmedizin. 2017 Nov 13;113(Suppl 1):7-12.
10. Rode B, Vučić M, Širanović M, Horvat A, Krolo H, Kelečić M, Gopčević A. Positive end-expiratory pressure lung recruitment: comparison between lower inflexion point and ultrasound assessment. Wiener Klinische Wochenschrift. 2012 Dec 1;124.
11. Futier E, Jaber S. Lung-protective ventilation in abdominal surgery. Current opinion in critical care. 2014 Aug 1;20(4):426-30.
12. Song IK, Kim EH, Lee JH, Ro S, Kim HS, Kim JT. Effects of an alveolar recruitment manoeuvre guided by lung ultrasound on anaesthesia-induced atelectasis in infants: a randomized, controlled trial. Anaesthesia. 2017 Feb;72(2):214-22.
13. Lutterbey G, Wattjes MP, Doerr D, Fischer NJ, Gieseke Jr J, Schild HH. Atelectasis in children undergoing either propofol infusion or positive pressure ventilation anaesthesia for magnetic resonance imaging. Pediatric Anesthesia. 2007 Feb;17(2):121-5.
14. Song IK, Kim EH, Lee JH, Ro S, Kim HS, Kim JT. Effects of an alveolar recruitment manoeuvre guided by lung ultrasound on anaesthesia-induced atelectasis in infants: a randomized, controlled trial. Anaesthesia. 2017 Feb;72(2):214-22.

15. Vitale V, Ricci Z, Gaddi S, Testa G, Toma P, Cogo P. Lung ultrasound profile after cardiopulmonary bypass in paediatric cardiac surgery: first experience in a simple cohort. Interactive cardiovascular and thoracic surgery. 2017 Apr 1;24(4):598-602.
16. Cantinotti M, Giordano R, Scalese M, Marchese P, Franchi E, Viacava C, Molinaro S, Assanta N, Rosenberger M, Kutty S, Gargani L. Prognostic value of a new lung ultrasound score to predict intensive care unit stay in pediatric cardiac surgery. The Annals of Thoracic Surgery. 2020 Jan 1;109(1):178-84.