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ORIGINAL RESEARCH

Lung analysis in children mechanically ventilated with atelectasis after cardiac surgery

Análise pulmonar em crianças mecanicamente ventiladas com atelectasia após cirurgia cardíaca

Análisis pulmonar en niños mecánicamente ventilados con atelectasia después de cirugía cardiaca

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ABSTRACT | The main objective of this study is to associate the healthy area of the lung (evaluated by radiography) with the data of respiratory mechanics in children with atelectasis after cardiac surgery, under mechanical ventilation in the assisted controlled mode. Altogether, 46 children were selected, but 16 were excluded due to irregular respiratory waves or lack of the data on arterial blood gases. A group of 30 children under assisted controlled mode were analyzed, and 10 from this group developed atelectasis. The data were analyzed before and after the onset of atelectasis, and respiratory mechanics was correlated to radiography. We also analyzed the data related to arterial blood gas of these children – who initially had no pulmonary complication – to verify possible changes due to assisted controlled cycles. Atelectasis may modify some parameters of respiratory mechanics. In the association of the healthy area of the lung with the respiratory mechanics, the Spearman correlation results showed statistical significance of the lung area with airway resistance ($\rho=-0.648$ and $p=0.043$). Our results show that it is possible to analyze respiratory mechanics waves by selecting controlled cycles in the assisted controlled mode, since we found insignificant changes in potential ionic hydrogen. The analysis of respiratory mechanics allows checking lung function and undesired lung injuries; the analysis of respiratory mechanics can be daily performed in these children to have important information on the pulmonary function. Our research also showed that under the assisted controlled mode is also possible to evaluate respiratory mechanics.

Keywords | Pulmonary Atelectasis; Pediatric Thoracic Surgery; Respiratory Mechanics; Blood Gas Analysis; X-Rays.

RESUMO | O objetivo deste estudo é associar a área saudável do pulmão (avaliada pela radiografia) aos dados de mecânica respiratória em crianças no pós-operatório de cirurgia cardíaca, com atelectasia em ventilação mecânica no modo assistido controlado. No total, foram selecionadas 46 crianças, das quais 16 foram excluídas devido às ondas respiratórias irregulares ou à falta de dados da gasometria arterial. Foi analisado um grupo de 30 crianças em modo assistido controlado, sendo que 10 crianças desenvolveram atelectasia. Os dados foram analisados antes e após o início da atelectasia, e a mecânica respiratória foi correlacionada às medidas da área do pulmão. Nas 30 crianças, inicialmente sem complicação pulmonar, foram analisados os dados da gasometria arterial para verificar possíveis mudanças devido aos ciclos assistidos. A atelectasia pode modificar alguns parâmetros da mecânica respiratória. Na associação da área saudável do pulmão com a mecânica respiratória, os resultados da correlação de Spearman mostraram significância estatística entre a área do pulmão com a resistência das vias aéreas (ρ=-0,648 e p=0,043). Os resultados demonstraram que é possível a análise das ondas de mecânica respiratória através da seleção

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dos ciclos controlados, uma vez que não houve alteração significativa no potencial de hidrogênio iônico. A análise da mecânica respiratória permite verificar a função pulmonar e as possíveis lesões pulmonares. A análise da mecânica respiratória pode ser usada diariamente nessas crianças, permitindo obter informações importantes da função pulmonar. O estudo também mostrou que no modo ventilatório assistido controlado também é possível avaliar a mecânica respiratória.
Descritores | Atelectasia Pulmonar; Cirurgia Torácica; Mecânica Respiratória; Gasometria; Raios X.

RESUMEN | El objetivo de este estudio es asociar la área sana del pulmón (evaluado mediante radiografía) a los datos de mecánica respiratoria en niños en el postoperatorio de cirugía cardiaca, con atelectasia en ventilación mecánica en el modo asistido controlado. En el total, fueron seleccionados 46 niños, de los cuales 16 fueron excluidos debido a las ondas respiratorias irregulares o a la falta de datos de la gasometria arterial. Se analizó un grupo de 30 niños en el modo asistido controlado, de los cuales 10 han desarrollado atelectasia. Los datos fueron analizados antes y después del inicio de la atelectasia, y la mecánica respiratoria se correlacionó a las medidas del área del pulmón. En los 30 niños inicialmente sin complicación pulmonar fueron analizados los datos de la gasometria arterial para comprobar posibles cambios debido a los ciclos asistidos. La atelectasia puede modificar algunos parámetros de la mecánica respiratoria. En la asociación del área saludable del pulmón con la mecánica respiratoria, los resultados de correlación de Spearman demostraron significancia estadística entre el área del pulmón con la resistencia de las vías aéreas (ρ=-0,648 y p=0,043). Los resultados mostraron que es posible el análisis de las ondas de mecánica respiratoria a través de la selección de los ciclos controlados, puesto que no hubo alteración significativa en el potencial de hidrógeno iónico. El análisis de la mecánica respiratoria permite comprobar la función pulmonar y las posibles lesiones pulmonares. Es posible utilizar el análisis de la mecánica respiratoria diariamente en estos niños, permitiendo obtener informaciones importantes de la función pulmonar. El estudio también mostró que en el modo de ventilación controlada es posible evaluar la mecánica respiratoria.
Palabras clave | Atelectasia Pulmonar; Cirugía Torácica; Mecánica Respiratoria; Análisis de los Gases de la Sangre; Rayos X.

INTRODUCTION

Congenital heart defects are the leading causes of newborn mortality. In the United States, around 35,000 babies are born alive with congenital heart disease each year. Of which, 10,000 need heart surgery before one year old1. In Brazil the number is 8 to 10 for every 1,000 born alive[2,3]. These babies usually do not reach adulthood without any surgical procedure[2,4-5], whereas only 20% of them have spontaneous healing[3], which requires attention in the postoperative cardiac surgery and Intensive Care Unit (ICU).

Pulmonary complications are common in the postoperative cardiac surgery, being the causes of morbidity and mortality in these patients[6,7]. The most common pulmonary complications in the postoperative period after congenital cardiac surgery are atelectasis and microatelectasis, pleural effusion, bronchospasm, pneumonia and pneumothorax[8]. These complications should be avoided to remove the child from Invasive Mechanical Ventilation (IMV) as soon as possible.

Many of the studies involving analysis of respiratory mechanic devices are performed in patients who are under the effect of sedation and controlled mode in the mechanical ventilation to exclude the interference of the patient in the ventilation and evaluation[9-12]. Although these children generally remain alive for 1 to 2 days under sedatives, after that, ventilation mode is changed to assisted controlled mode to allow the active influence of the child on respiratory cycle.

The X-ray examination should be avoided, but in clinical practice it is often performed. Ionizing radiation performed by X-ray apparatuses may cause complications and somatic effects later on children since they are more sensitive and vulnerable to radiation[13-14]. Ensuring safety and respecting the minimum doses required for this exam without adversely affecting the information obtained is extremely important for good results13. However, we hypothesize that respiratory parameters can reduce the X-ray evaluation rate.

The main purposes of this study were to correlate the healthy area of the lung, through radiograph images, with respiratory parameters in children with atelectasis in postoperative cardiac surgery. Thus, physical lung changes correspond to functional changes through respiratory mechanics, and this type of pulmonary analysis was incorporated by the Physiotherapy team. A secondary objective was to analyze the respiratory mechanics in assisted controlled mode in comparison with changes in arterial blood gases, analyzing the possible changes that assisted cycles can influence and change the blood gases analysis.

METHODOLOGY

The study was approved by the Ethics and Research committee of the Hospital Pequeno Príncipe, Curitiba, Brazil, under registration number 1034-11. The parents signed a free and enlightened consent form and an authorization for the research that was carried out in the hospital's cardiac critical care unit (from January to August, 2012).

In the period analyzed we selected all children in cardiac ICU within the inclusion criteria: age between 0-12 months in a postoperative cardiac surgery situation in the IMV; the exclusion criteria were children with neurological problems, children that were not in a controlled or assisted controlled mode, and children with great hemodynamic instability. During the study period we selected 46 children of both gender, aged 0-12 months, and 16 of them were excluded due to irregular respiratory waves or lack of arterial blood gases data. Groups of 30 children (20 boys and 10 girls) were in assisted controlled mode, not having any pulmonary complication in the initial period in ICU. Ten out of these children developed atelectasis during the ICU period (age 2.25±1.62 months), and 20 children who had other pulmonary complications were excluded – such as pneumothorax and pleural effusion, irregular respiratory signals or lack of arterial blood gases data. Samples for arterial blood gas analysis were obtained from a catheter in the radial artery with a heparinized syringe (Monovette® LH; Sarstedt, Nümbrecht, Germany). The equipment used for analysis was Cobas B121 system (Roche Diagnostics®, Mannheim, Germany) that was daily calibrated.

Respiratory mechanics data were acquired by mechanical ventilator Inter® 5 plus and the Inter® GMX graphic monitor, both from the Intermed, through the use of a flow sensor to capture and storage the data, related later to the pressure variation. For flow, pressure and volume we used Wintracer® software (Intermed). Respiratory mechanics data were obtained almost simultaneously with radiographic examination and arterial blood analysis. These procedures were daily performed for each child during their staying at ICU. At the end of child's period in the ICU, most representative radiographs and respiratory waves were chosen. Children who developed atelectasis were analyzed separately, and their radiographs were examined before and after lesions. For the analysis of the lung area, we used AutoCad® 2012, in which the projection of parts without atelectasis was visually defined, being classified as functional areas of the lung. The axillary distance and height of the child's lung was used to establish a calibration of the measures in AutoCad® 2012 (Figure 1).

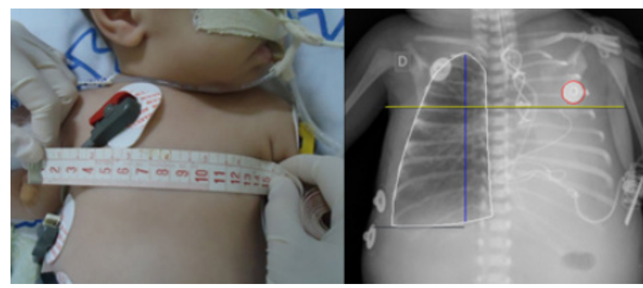

Figure 1. Analysis of the lung area with the AutoCad® 2012 program

Statistical analysis was performed using the SPSS® (version 18). The normality test Shapiro-Wilk was used, and presented non-normal distribution in the groups. It was applied non-parametric statistics, Mann-Whitney test to non-paired group, Wilcoxon test to paired group and Spearman to correlation coefficient.

RESULTS

All children were analyzed in the assisted controlled mode. The characteristics of the group without lung injury are shown in Table 1. The pulmonary complication most frequent during Invasive Mechanical ventilation (IMV) was atelectasis, followed by pleural effusion and pneumothorax.

Before injury, we verified a significant change compared with normal arterial blood gases and no changes in the blood's potential ionic hydrogen (pH). In the arterial partial pressures of carbon dioxide ($PaCO_2$), we found a mild hypercapnia, but this small increase in $PaCO_2$ did not significantly altered the pH (significance threshold used was p=0.05). The bicarbonate (HCO_3^-) also showed no significant change compared to normal values, with the majority within the normal range. The biggest change compared with normal values was in partial PaO_2 (Table 2).

Table 1. Descriptive characteristics of the group without lung injury (n=30)

Variables	Mean±sd	Minimum – Median – Maximum
Age (months)	3.23±2.52	0.5–2–9
Weight (kg)	4.29±1.46	2.25–3.94–7.33
Time in IMV (days)	2.43±1.97	1–2–9
VT (ml)	50.22±23.27	3.9–50.22–97.9
PPEAK (cmH_2O)	25.39±4.93	17.6–25.05–35.5
PPLAT (cmH_2O)	21.16±4.61	14.4–22.11–31.2
PEEP (cmH_2O)	6.02±1.26	4.6–6–10.1
Cst (ml/cmH_2O)	3.54±2.10	0.22–3.25–9.02
Cdyn (ml/cmH_2O)	2.64±1.45	0.02–2.53–5.98
Surface Lung Area (cm^2)	84.98±23.18	30.92–88.12–135.3
Raw (cmH2O/L/seg)	41.61±16.74	16.64–38.87–77.33
RR (bpm)	25.43±6.18	18–23.5–41
pH	7.36±0.06	7.2–7.39–7.5
$PaCO_2$ (mmHg)	43.87±8.26	31.4–40.1–64.3
PaO_2 (mmHg)	124.99±60.78	33.4–141.9–255.4
HCO_3- (mEq/L)	24.12±4.71	11.7–23.2–39.1
SaO_2 (%)	93.17±10.01	64.1–99.15–99.9

Abbreviations: V_T – tidal volume; RR – respiratory rate; $P_{PEA}K$ – peak pressure; P_{PLAT} – plateau pressure; PEEP – positive end-expiratory pressure; C_{dyn} – dynamic compliance; C_{st} – static compliance; R_{aw} – airway resistance; pH – potential hydrogen; $PaCO_2$ – partial pressure of arterial carbon dioxide; PaO_2 – partial pressure of arterial oxygen; HCO_3 -bicarbonate; SpO_2 – oxygen saturation; mmHg – millimeters of mercury; ml – milliliter; mL/kg – milliliter per kilogram; bpm – breaths per minute; s – seconds; cmH_2O – water centimeter; l/min – liters per minute; ml/cmH_2O – milliliter per water centimeter; cm^2 – square centimeter; mEq/L – milliequivalents per liter

*Significant difference at a significance level of p<0.05

Table 2. Comparison of the group without lung injury with the normal values (n=30) using the Wilcoxon (W) test (n=30)

Variables	Reference value	p
pH	7.4 (7.35-7.45mmHg)	0.36
$PaCO_2$	40 (35-45mmHg)	0,0449*
PaO_2	90 (80-100mmHg)	0,006*
PaO_2 (1-6months)	72.5 (60-85mmHg)	0.001*
HCO_3^-	24 (22-26mEq/L)	0.8936

*Significant difference at a significance level of p<0.05

The data show no significant pH change in these children without lung injury in IMV, showing that the assisted-controlled ventilation mode did not influenced the blood gas analysis, which presented only mild hypercapnia ($PaCO_2$) – the accumulation of carbon dioxide (CO_2) can occur due to hypoventilation. Thus, the children's Respiratory Rate (RR) decreased and they could not eliminate this CO_2. It is probable that assisted breath was not enough to alter the data on the blood gas analysis because few inspiratory intentions were captured.

Regarding RR in children without lung injury, the average was 25.43bpm, which takes into account that this estimated RR for the age group is below the expectance for the average during 3.23 months (30-35 bpm for children with 3 months of age). This could lead to a slight increase in CO_2 levels.

Among the groups with atelectasis, the reduction of parameters statistically significant was the Tidal Volume (TV), surface lung area and PaO_2, and the increase of RR and Time in IMV. In the group with atelectasis, RR had a significant increase (p=0.025), with higher respiratory effort. The results that had statistical significance using the Wilcoxon test to compare the groups without/with atelectasis are presented in Figures 2 and 3, and the descriptive characteristics of the atelectasis group are presented in Table 3.

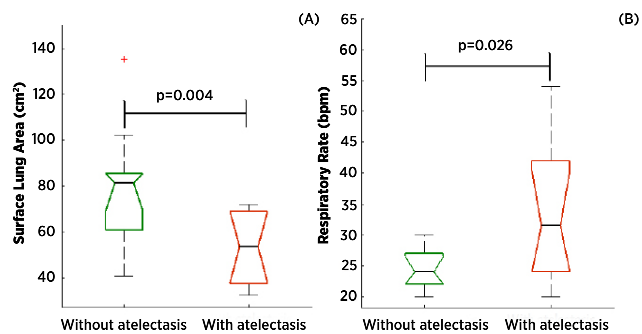

Figure 2. Significant reduction in (A) surface lung area and significant increase in (B) respiratory rate in the groups with and without atelectasis

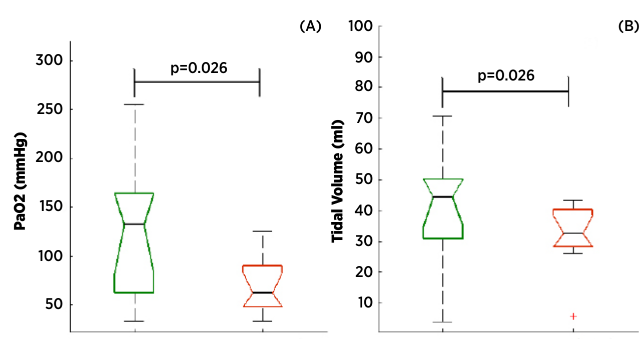

Figure 3. Significant reduction in (A) PaO2 and in the (B) tidal volume in the group with and without atelectasis

The static and dynamic compliance did not showed statistically significant change after atelectasis, which showed slight increase in static compliance (C_{st}) (2.66 to 2.76ml/cmH_2O) and a slight decrease in dynamic compliance (C_{dyn}) (2.07 to 2.01ml/cmH_2O), and both of them are below normal values for the age (5 to 10ml/cmH_2O). Although airway resistance (R_{aw}) had not significant changes, it has increased in the group with atelectasis (37.63 to 49.03cmH_2O/L/s). The group had higher values compared with the normal values for the age (10 to 20cmH_2O/L/s). In the group without lesion, the R_{aw} also increased(41,61±16,74cmH_2O/L/s).

The results of the Spearman coefficient (ρ) showed statistical significance between the surface lung area and the R_{aw} parameters (ρ=-0.648 with p=0.043) for the group with atelectasis point, whereas the group with atelectasis had a negative moderate correlation. This means that the smaller the area of the lung, the greater the value of R_{aw}.

Table 3. Comparison between before and after the appearance of the atelectasis

Variables	Before atelectasis (n=10)	After atelectasis (n=10)	Wilcoxon test (W)
	Mean±sd	Mean±sd	p
Age (months)	2.25±1.62	-	-
Weight (kg)	3.68±0.95	-	-
V_T (ml)	42.54±19.09	31.403±10.79	0.026*
P_{PEAK} (cmH_2O)	26.61±4.48	24.342±6.47	0.113
P_{PLAT} (cmH_2O)	23.2±3.75	21.24±6.23	0.751
PEEP (cmH_2O)	6.51±1.17	6.35±1.29	0.752
C_{st} (ml/cmH_2O)	2.66±1.37	2.762±2.28	0.342
C_{dyn} (ml/cmH_2O)	2.07±1.28	2.016±1.18	0.343
Surface Lung Area (cm^2)	79.46±26.6	52.251±15.60	0.004*
Raw (cmH_2O/L/seg)	37.63±14.79	49.031±31.22	0.752
RR (bpm)	24.3±3.26	34.3±11.20	0.026*
pH	7.35±0.08	7.3383±0.09	1.000
$PaCO_2$ (mmHg)	46.81±11.16	45.45±7.60	0.751
PaO_2 (mmHg)	129.67±68.68	72.13±30.98	0.026*
HCO_3^- (mEq/L)	24.44±7.46	23.46±4.60	0.752
SaO_2 (%)	93.88±9.65	80.36±23.93	0.113

*Significant difference at a significance level of p<0.05

DISCUSSION

This study showed that some parameters of respiratory mechanics decreased and other increased due to atelectasis, but this also may be related to the cardiac surgical procedure itself. The lung function is altered by pulmonary complications as well as by the surgical procedure and mechanical ventilation itself[15]. Static compliance may be reduced compared with normal values for each age group due to a cardiac surgery[16].

The R_{aw} can increase due to injury and pulmonary edema, presence of secretions and loss of lung volumes[17,18]. This increase in airway resistance is common during surgery and return to normal values after the procedure[19].

Another parameter of respiratory mechanics showed that change was V_T. As a protective measure, the V_T should be below 6ml/kg[10], therefore the V_T between these values was not associated with increased mortality, being used as margin trust[20]. Dividing the value of the V_T by weight, both groups (with/without atelectasis) and the group without lung injury had values above recommended for V_T – thus, this parameter should be considered a protective measure in an ICU.

Regarding the main objective of this study, which was to correlate the healthy area of the lung through X-ray to pulmonary function by respiratory mechanics, it had statistical significance between the surface lung area and the respiratory parameters for the atelectasis group, which were the R_{AW} parameters (ρ=−0.648 and p=0.043). We observed that the smaller the area of the lung, the greater the value of R_{AW}. This correlation of the physical with the functional aspect is normally not checked, and we found few studies about the subject. Therefore, this study brings new data that can improve pulmonary analysis in children in IMV, since many factors can affect respiratory mechanics (e.g., X-ray). A single study consisting of high-resolution images from computed tomography compared the respiratory mechanics of newborns with very low weight, aiming at to find an association between lung mechanics and structural changes of the lung parenchyma, and proving thus the relationship between the lung morphological structure and functional alterations in asymptomatic infants of very low birth weight[21].

The analysis of respiratory mechanics provides a functional assessment of the lung in these children, showing the staying in IMV as well as the surgical procedure can lead to functional changes. The mechanical evaluation of respiratory wave is a visual procedure, creating inter-subjects differences on results, and both analyses provide important information about pulmonary function. The monitoring of respiratory mechanics continues gaining importance, especially in relation to knowledge and management of the lungs with acute injury[22].

Although the data presented changes before and after the appearance of atelectasis, many had no statistical power, even with changes in all parameters – probably due to the sample size. A study with a larger number of subjects would be interesting to check if changes occur before and after the onset of pulmonary complications and with the correlation between pulmonary function and physical changes of the lung.

CONCLUSION

The daily analysis of respiratory mechanics allowed us to verify the functional changes of the lung, analyzing changes both due to pulmonary complications and the surgical procedure.

Only one parameter was related to physical changes in the lung, making room for other studies in this area, since the number of this sample was small and this factor should be considered. Although the health area evaluated for X-ray shows correlation with only one mechanical parameter – airway resistance ($\rho=-0.648$ and $p=0.043$) –, it is not viable to reduce the X-ray acquisition rate to perform pulmonary assess and reassessment.

Most studies involving respiratory mechanics suggest the controlled mode and sedation as the best options, but the assisted controlled mode is also possible to perform this analysis, since the children of our study showed no considerable changes in relation to arterial blood gases. Moreover, this procedure can be daily performed with the monitoring of the child on an ICU bed.

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