CRITERIA FOR SUCCESSFUL WEANING FROM MECHANICAL VENTILATION IN CHILDREN

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ABSTRACT

The aim of the research was to establish criteria for successful weaning from mechanical ventilation in children based on analysis of Paediatric rapid shallow breathing index, maximum amplitude of diaphragm movements, diaphragm thickening fraction and pressure support (PS), which ensure minimal respiratory muscle load, level of consciousness which ensure minimal respiratory muscle load and presence of cough and swallowing reflexes and previous unsuccessful attempts of weaning.

Investigated problem: there is no consensus on the basic physiological parameters for successful extubation that have to be achieved during weaning from mechanical ventilation in children due to variability in size and degree of maturity of lungs and patients' comorbidities. It leads to the lack of clinical justification for the routine practice of weaning in children.

The main scientific results: We have established a list of causes of unsuccessful weaning depending on the function of the diaphragm in children with different types of respiratory failure.

We have clarified and supplemented the list of reasons for unsuccessful weaning from mechanical ventilation depending on nutritional status and level of serum electrolytes in children.

We have identified and supplemented the list of reasons for unsuccessful weaning from mechanical ventilation depending on the disorders of neurological status in children.

We have supplemented the algorithm for predicting difficult weaning from mechanical ventilation in children.

The area of practical use of the research results: the obtained results have to increase the rate of successful weaning in children with acute respiratory failure in pediatric intensive care units.

1. Introduction

1. 1. The object of research

The object of research was to establish criteria for successful weaning from mechanical ventilation in children based on analysis of Paediatric rapid shallow breathing index, maximum amplitude of diaphragm movements, diaphragm thickening fraction and pressure support (PS), which ensure minimal respiratory muscle load and level of consciousness, presence of cough and swallowing reflexes and previous unsuccessful attempts of weaning.

1. 2 Problem description

Acute respiratory failure is one of the most common cause of death among children in pediatric intensive care units (PICU) [1]. No matter what is the etiology of this syndrome, from 30 % to 64 % of children in PICU need mechanical ventilation (MV), and unsuccessful weaning might be present in 6.2 % [2] to 36 % [3, 4] of them. Both the early start of weaning and its delay are harmful to patient. Early extubation can lead to catastrophic circulatory or respiratory disorders, and long-term mechanical ventilation with high parameters in 29–80 % of patients is associated with atrophy and dysfunction of diaphragm [5]. Last decade represents us not only animal models, which illustrate how diaphragm activity during MV support can attenuate ventilator-induced diaphragmatic dysfunction [6], but also human studies which confirm that length of MV is associated with the degree of diaphragm atrophy [7].

There is also important to identify and prevent potential routes of diaphragmatic injury with providing diaphragm-protective strategy of mechanical ventilation. In addition, there is no consensus on the basic physiological parameters for successful extubation that have to be achieved during weaning from mechanical ventilation in children due to variability in size and degree of maturity of lungs and patients' comorbidities. It leads to the lack of clinical justification for the routine practice of weaning in children.

1. 3. Suggested solution to the problem.

The described problem can be solved with making the analysis of criteria which ensure minimal respiratory muscles load during weaning from MV. The working hypothesis was that Paediatric rapid shallow breathing index, maximum amplitude of diaphragm movements, diaphragm thickening fraction and pressure support (PS) can not predict results of weaning from MV in children.

2. Materials and Methods

We conducted a prospective cohort single-center study at the Department of Anesthesiology and Intensive Care at Lviv Regional Children's Clinical Hospital "OHMATDYT" from January 2018 till April 2020. We included patients with acute respiratory failure who was mechanically ventilated for more than 3 days. Exclusion criteria for the study were: the refusal of the patient's legal representatives to participate in the study at any of its stages, the patient's agonizing state upon admission, and the onset of MV less than 48 h after prior weaning.

The study included 89 patients aged 1 month – 18 years. All patients were randomly divided into 2 groups (using random.org). Group I included patients who received lung-protective ventilation strategy, group II – patients who received diaphragm-protective in addition to lung-protective ventilation strategy. 82 patients were included in the data analysis. We studied indicators of diaphragm function (amplitude of diaphragm movement, thickening fraction and it was considered that decreasing of this indicator less than 15 % was a marker of diaphragm weakness; increasing it up to 35 % and more was a marker of high respiratory function and a potentially damaging factor for diaphragm), acid-base balance changes and parameters of MV (spontaneous respiratory rate, total minute volume ventilation and spontaneous minute volume ventilation and it comparison with total minute volume ventilation, minimal pressure support, which was need for absence respiratory muscles overload), Paediatric rapid shallow breathing index, Glasgow coma scale level, presence of cough and swallowing reflexes and previous unsuccessful attempts of weaning.

To assess age-dependent data, patients were divided into age subgroups: 1st subgroup – children 1 month – 1 year; 2nd subgroup – children 1–3 years; 3rd subgroup – children 3–6 years; 4th subgroup – children 6–13 years; 5th subgroup – children 13–18 years.

Stages of the study: 1st day (d1), 3rd day (d3), 5th day (d5), 7th day (d7), 9th day (d9), 14th day (d14), 28th day (d28).

The primary endpoint was the duration of weaning from MV. Secondary endpoints were trends in Paediatric rapid shallow breathing index and rate of complications: frequency of reintubations and tracheostomies, prolonged mechanical ventilation, death (we assessed the presence of these adverse events daily from the time of inclusion of the patient in the study, 28 days after clinical, laboratory and instrumental signs of acute respiratory failure till discharging patient from the hospital).

3. Results

We found that restoration of spontaneous breathing occurred significantly faster in II group in all age subgroups of patients in comparison with the I group. It was confirmed by a significantly faster increasing of rate of spontaneous breathing in II group. These indicators were (**Fig. 1**) for the I and II groups at stage d1 – 4 [3; 5] breath/min and 6 [5; 7] breaths/min (p=0.12), at stage d3 in II group data were in 2 times higher than in I group (16 [14; 18] breaths/min and 8 [6; 9] breaths/min, p=0.05),. At stage d7 and d9 in II group they were 22 [20; 24] breaths/min and 24 [21; 28] breaths/min, in comparison with 14 [13; 15] breaths/min and 16 [14; 17] breaths/min in I study group (p=0.01 and p=0.04)

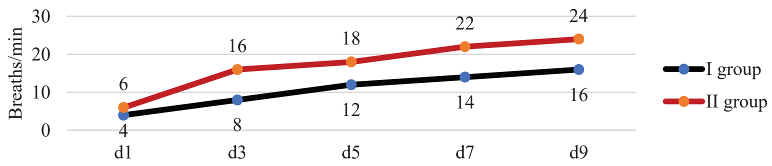

Fig. 1. Changes of spontaneous respiration rate during MV in 1st age subgroup

The spontaneous minute volume ventilation in 1st age subgroup of patients was significantly higher in II group at stages d3, d7 and d9 in 2 times, 2.5 times and 2.1 times in comparison with I group (p=0.05; p=0.002 and p=0.002).

In 2nd age subgroup (**Fig. 2**) in II group at the stage d1 the frequency of spontaneous breaths was 16 [6; 18] breaths/min in comparison with 6 [2; 10] breaths/min in group I (p=0.04); at stage d3 in group II this parameter increased to 25 [12; 26] breaths/min, in comparison with 9 [5, 14] breaths/min in group I (p=0.02). Further to stage d7, the frequency of spontaneous breaths did not increase significantly in group II, while in group I this tendency to a gradual increasing was maintained.

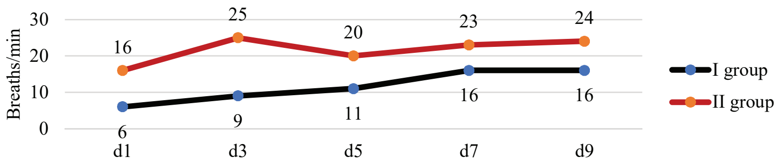

Fig. 2. Changes of spontaneous respiration rate during MV in 2nd age subgroup

The minute volume of spontaneous ventilation was significantly different in both groups of patients from the stage d3, when in group I it was 1.0 [0.65; 1,225] l/min, in comparison with 1.9 [1,885; 2.12] l/min (p=0.02) in group II; at stage d5 these indicators were 0.964 [0.845; 1.12] l/min in I group and 2.2 [2.14; 2.45] l/min in II group (p=0.001). This shows the restoration of proper function of spontaneous respiration pattern and active coordinated work of respiratory muscles. At the stage d7, the minute volume of spontaneous ventilation in II group was in 1.6 times higher than in I group (2.55 [2.43; 2,855] l/min in II group and 1,554 [1,16; 1.942] l/min in I group (p=0.04).

In the 3rd age subgroup (**Fig. 3**), the frequency of spontaneous respiration was significantly higher in II group and at stage d5 was 29 [20; 30] breaths/min in group II, and 14 [11; 16] breaths/min in group I (p=0.02); at stage d7 – 25 [22; 27] breaths/min in comparison with 14 [12; 18] breaths/min (p=0.04) and at stage d9 – 21 [19; 25] breaths/min in comparison with 12 [10; 13] breaths/min (p=0.02).

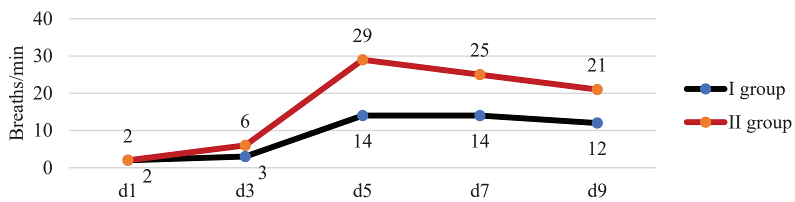

Fig. 3. Changes of spontaneous respiration rate during MV in 3rd age subgroup

Among patients of the 3rd age subgroup, the volume of spontaneous ventilation significantly faster increased in II group from stage d3 to stage d9 of patients, in comparison with I group.

The frequency of spontaneous respiration in 4th subgroup (**Fig. 4**) in II group at stage d3 was 8 [6; 12] breaths/min, and 0 [0; 4] breaths/min (p=0.02) in I group; at d5 – 8 [5; 10] breaths/min and 0 [0; 5] breaths/min (p=0.01), at stages d7 and d9 in group I increased to 5 [4; 8] breaths/min and returned to 3 [2; 6] breaths/min, while in group II was 9 [5; 10] breaths/min and 12 [4; 14] breaths/min (p=0.05 and p=0.001), respectively.

Significant differences were found in the data of spontaneous minute volume ventilation in 4th age subgroup: it was almost absent on stage d5 in I group and gradually increased from stage d1 to stage d5 in II group.

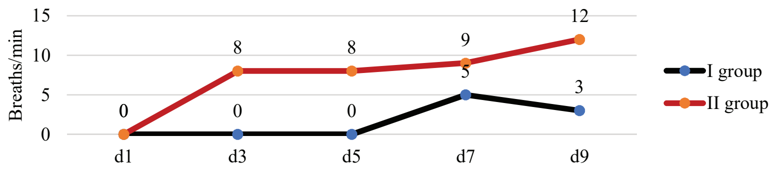

Fig. 4. Changes of spontaneous respiration rate during MV in 4th age subgroup

In the fifth age subgroup (**Fig. 5**) there were significantly faster increase in spontaneous minute volume ventilation due to both the frequency of spontaneous breaths and, apparently, an increase in lung compliance in patients of II group, in comparison with I group from stage d3 to stage d7. Thus, already at stage d3 spontaneous minute volume ventilation was 1.93 [1.645; 2.97] l/min in group II, and 0.76 [0; 1.59] l/min in group I (p=0.04); at stage d5 increased to 3.735 [0,293; 7,695] l/min in group II and up to 2.4 [0.255; 2.84] l/min in group I (p=0.05); at the stage d7 it was 4 [3.3; 4.51] l/min in group II, and 2.6 [0.985; 2.96] l/min in group I (p=0.02).

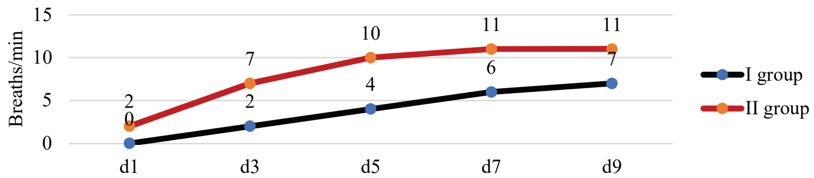

Fig. 5. Changes of spontaneous respiration rate during MV in 5th age subgroup

Summarizing all the above, spontaneous minute volume ventilation in II group of patients in all age subgroups increased significantly highly and faster in comparison with patients in I group. Moreover, in the II group readiness for weaning from mechanical ventilation as a presence of 75 % and more of spontaneous minute volume ventilation to the total minute volume ventilation was achieved in 1st age subgroup – at d7 stage; in 2nd age subgroup – at the d3 stage, in 3rd age subgroup – at d5 stage; in the 4th and 5th age subgroups – only at stage d9; while in I group among all age subgroups of patients this indicator was not achieved even to step d9.

We identified age-specific features of diaphragm dysfunction during MV: in patients of the first age subgroup in group I there were found weakness for the right hemidiaphragm with compensatory excessive level of work for the left dome at the beginning of weaning and at stage d9, while in group II diaphragm overload was registered only at stage d5. In patients of 2nd age subgroup in group I changes were the opposite to described previous – we found excessive work of the right hemidiaphragm with low contractions of left dome at all stages of study in I group, while in II group – the only episode of diaphragmatic weakness in stage d3. In the 3rd age subgroup the proper diaphragmatic activity in I group of patients was restored later than in II group. In the 4th age subgroup in I group there was episode of high work of a diaphragm at stage d5, whereas in II group – all data of diaphragm function were within the recommended parameters for diaphragm-protective strategy of MV at all stages of our study. In the 5th age subgroup in I group excessive work of both right and left domes of diaphragm was significantly more often registered during weaning than in II group, however, in II group were found episodes of both type changes – diaphragmatic weakness and excessive work.

We studied the presence of cough and swallowing reflexes in patients of both groups and obtained the following results: among patients of group I at study stages d1, d3, d5, these indicators were 75.3 %, 79 %, 82.7 %, and 83.9 %, and from the stage of the study d7 they did not change were 83.9 %. In II patients group these data were 80 % (p=0.28) at stage d1; 85.9 % (p=0.12) on d3, 87.3 % (p=0.23) on d5; and 88.7 % on d7 (p=0.41).

It was found that combination of such indicators as Paediatric rapid shallow breathing index>6.2 breaths/min/ml/kg (AUC=0.739, 95 % CI=0.618–0.861; p=0.001) with 70 % sensitivity and 79.1 % specificity for successful extubation), amplitude of the diaphragm movement less than 8 mm, fraction of diaphragm thickening less than 15 % or more than 35 %, tidal volume less than 4.5 ml/kg, PS more than 12 cm H_2O to achieve minimal respiratory system load, no spontaneous cough reflex, less than 11 points according to Glasgow coma scale, and two or more previously unsuccessful weaning attempts give us unfavourable prognosis for weaning from mechanical ventilation. In addition, it was found that for patients with hypoxemic and combined hypercapnic-hypoxemic type of acute respiratory failure in the presence of bulbar disorders and inability to swallow liquid food, the prognosis for weaning was favourable in case of securing lower airways with a cuffed tube with maintenance pressure in a cuff not less than 15–20 mm Hg.

4. Discussion

It is known that muscle atrophy frequently occurs in children admitted to ICU [10] and diaphragmatic with other skeletal muscle atrophy and weakness are associated with difficulty weaning from MV [5].

However, historically adequacy of spontaneous ventilation is checked only during spontaneous breathing trial test, via T-tube or some different devices, and it gives the only confirmation of patients' readiness to be weaned from MV on time of extubation [11]. We suggest observing spontaneous respirations adequacy all the time since we stop sedation and gradually decrease support parameters of MV. It will improve our clinical judgment how to wean this patient as soon as possible and safe.

We also know, that it is recommended that all children on respiratory support preferably should breathe spontaneously, with the exception of the most severely ill child with obstructive airway (strong agreement), restrictive (strong agreement) or mixed disease (strong agreement) requiring very high ventilator settings and intermittent neuromuscular blockade (strong agreement) [12]. Therefore, good diaphragmatic activity [8] with providing enough level of spontaneous minute volume ventilation [9] have to improve clinical outcomes in mechanical ventilated children. However, it is unknown the sufficient spontaneous respirations rate to achieve it.

Our study identified possible mechanisms of spontaneous breathing inadequacy and the causes of unsuccessful weaning from mechanical ventilation in children in accordance to diaphragm function and rate of spontaneous respirations.

It was found that the recovery of spontaneous respiration occurred significantly faster in the II study group of all age subgroups of patients compared with the I study group, which is confirmed by a significantly faster increase in spontaneous respiration rate, significantly faster growth of spontaneous minute volume ventilation among patients of the II group of all age subgroups, faster achievement of readiness for weaning due to the presence of 75 % of spontaneous minute volume ventilation (among children of the 2nd age subgroup it was achieved already at the stage d3, among patients of the 3rd age group – at the stage d5; among patients of the 1st age group – at the stage of d7; in the 4th and 5th age subgroups only at stage d9, while in study group I among all age subgroups of patients was not reached to stage d9) .We found that in II group at stages d3 and d5 were low levels of thickening fraction of right hemidiaphragm (less than 15 %) with a frequency of their detection of 78 % at stage d3 and 59 % at stage d5, compared with 32 % and 17 % at similar stages among patients of study I group. Signs of excessive contraction of the right dome of the diaphragm (thickening fraction over 45–50 %) were in 67 % of patients in group I and only in 5 % patients in group II at the stage d7 (p=0.0001), which is the evidence of excessive diaphragm work in I group.

It was found that it was reduced the duration of mechanical ventilation: in patients of the 1st age subgroup by 1.5 times (p=0.08); in patients of 2nd age subgroup – by 2.4 times (p=0.18); in 4th age subgroup – by 1.75 times (p=0.1); in 5th age subgroup – by 4.25 times (p=0.009). In patients of 3rd age subgroup duration of mechanical ventilation increased by 1.1 times (p=0.68). The frequency of complications (reintubations) was reduced in 1st age subgroup by 4.3 times (p=0.02); in 2nd age subgroup – by 3.4 times (p=0.04). There were no significant differences in the frequency of tracheostomy among patients of I and II groups.

5. Conclusion

Amplitude of diaphragm movement over 8 mm with fraction of diaphragm thickening 15–35 % provide enough spontaneous minute volume ventilation in mechanically ventilated children. Moreover, pressure support over 12 cm H_2O allows to achieve minimal respiratory system load and Paediatric rapid shallow breathing index >6.2 breaths/min/ml/kg might be criterion for successful weaning. In addition, it is still needed to have cough reflex and more than 11 points according to Glasgow Come Scale to be successfully weaned.

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