REVIEW ARTICLE

Assessment and initial management of acute respiratory failure in children

Avaliação e manejo inicial da insuficiência respiratória aguda na criança

Jaisson Gustavo da Fonseca[1], Adrianne Mary Leão Sette e Oliveira[1], Alexandre Rodrigues Ferreira[2]

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ABSTRACT

Diseases of the respiratory system are some of the leading causes of child care in emergency services, with severity ranging from mild and self-limiting to life-threatening. Undetected acute respiratory failure is the main cause of cardiac arrest in children. The ability to recognize, produce an early diagnosis, and properly manage respiratory impairments in children are essential skills for doctors working in emergency services. The purpose of this article is to present an approach to systematic evaluation so as to enable early diagnosis and initial management of acute respiratory failure in children in emergency services.

Key words: Emergency Medicine; Respiratory Failure; Airway Management; Child.

RESUMO

O comprometimento do sistema respiratório é uma das principais causas de atendimento a crianças nos serviços de emergência, com a gravidade variando desde quadro leve e autolimitado até doença fatal. A insuficiência respiratória aguda não reconhecida é a principal causa de parada cardíaca na população pediátrica. A capacidade de produzir um diagnóstico precoce, reconhecer e manejar adequadamente o comprometimento respiratório em crianças é habilidade essencial para médicos que trabalham em serviços de urgência. O objetivo deste artigo é apresentar uma abordagem, por meio de uma avaliação sistemática, que permita diagnóstico precoce e manejo inicial do comprometimento respiratório agudo em crianças atendidas em serviços de emergência.

Palavras-chave: *Medicina de Urgência; Insuficiência Respiratória; Manuseio das Vias Aéreas; Criança.*

[1] Horizontal Care Physician of the Pediatrics ICU at the Hospital das Clínicas, Universidade Federal de Minas Gerais – UFMG. Instructor of the Pediatrics Advanced Life Support Course (*American Heart Association*). Belo Horizonte, MG – Brazil.
[2] Associate Professor at the Department of Pediatrics at the UFMG School of Medicine. Medical Coordinator of the Functional Pediatrics Unit. Instructor of the Pediatrics Advanced Life Support Course (*American Heart Association*). Belo Horizonte, MG – Brazil.

INTRODUCTION

Impairments to the respiratory system are some of the main causes for emergency care among children, with severity ranging from mild and self-limited to fatal.[1] The pediatric population is particularly susceptible to developing high severity respiratory disorders due to several interrelated factors that favor such progression ranging from anatomic peculiarities to physiological and immunological characteristics.[2]

Recognizing and adequately handling respiratory impairment in children are extremely relevant skills for physicians working in emergency care units. The purpose of this article is to present an approach to a systematic assessment of the initial handling of acute respiratory impairment in children in emergency care units. Treatment to the specific diseases causing the respiratory impairment is not discussed in this text.

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Institution:
Hospital das Clínicas da UFMG. Functional Pediatrics Unit
Belo Horizonte, MG – Brasil

Corresponding Author:
Alexandre Rodrigues Ferreira
E-mail: alexfer1403@gmail.com

CHILDREN PARTICULARITIES

Children have several particularities that make them more susceptible to developing respiratory failure, including:[2]

- small airway diameter, more prone to obstruction;
- immature intercostal and diaphragmatic muscle functions, making exhaustion more likely;
- underdeveloped collateral ventilation pores (Lambert Canals and Pores of Kohn), facilitating atelectasis formation;
- a more compliant rib cage;
- lack of thoracoabdominal coordination during REM sleep impairing bronchial hygiene;
- less elastin in the lungs of young children, leading to decreased elastic recoil and consequent decrease in lung compliance;
- immune system still in development, increasing the risk infections.

DEFINITIONS

The medical literature often uses the terms respiratory distress and respiratory failure to describe respiratory behavior. In this study we use the following concepts:

- **respiratory distress:** a clinical condition characterized by signs and symptoms of an abnormal respiratory pattern,[3] such as elevated respiratory rate (tachypnea) and increased respiratory effort (e.g., intercostal retractions);
- **respiratory failure:** inability for lungs to provide sufficient oxygen and remove enough carbon dioxide to meet the body's metabolic needs.[3]

This terminology can be understood as continuous and progressive phases of respiratory impairment. Respiratory distress is considered a compensation state in which the patient maintains proper gas exchanges from an increase in breathing labor and frequency.[3] When the child experiences exhaustion or a worsening of respiratory function that cannot be compensated, he or she enters respiratory failure.[3] In case of deterioration, either by the disease's natural course or because treatment is delayed or absent, the patient enters the cardiopulmonary failure phase which precedes cardiorespiratory arrest. Cardiopulmonary failure can be defined as respiratory failure associated with shock, requiring immediate intervention to stop cardiorespiratory arrest.[4]

It is important to highlight that respiratory problems may or may not progress in the sequence reported depending on the disease's natural progression or on the treatment implemented. Additionally, certain cases can present abrupt respiratory failure not preceded by respiratory distress, as in the case of airway obstruction by a foreign body.

TYPES OF RESPIRATORY FAILURE

Respiratory failure can be classified by its underlying pathophysiology or process duration.[3] The pathophysiological classification is based on O_2 and CO_2 content in arterial blood. The hypoxic respiratory failure (inadequate oxygenation) is defined as arterial $pO_2 < 60$ mmHg in ambient air, while hypercapnic respiratory failure (inadequate ventilation) is defined as arterial $pCO_2 > 50$ mmHg. It is important to highlight that both forms may coexist as a combined failure in oxygenation and ventilation.[3]

Classified according to the time criterion, respiratory failure is considered acute for rations of recent onset (hours or days) or chronic when the alterations develop over weeks or years.[2] In acute cases, physiological compensatory mechanisms are not yet in place, leading to acid-base imbalance.[2] In chronic cases, however, compensatory mechanisms can develop to improve O_2 transport (increased hemoglobin levels) and compensate respiratory acidosis (increased bicarbonate levels).[2]

SYSTEMATIC EVALUATION

Initial evaluation of patients with respiratory involvement, as with any other potentially severe clinical condition, can be carried out with the systematic approach proposed by the Pediatrics Advanced Life Support of the *American Heart Association* using the mnemonic ABCDE rule.[5] Because the focus of this research is respiratory involvement our discussion will focus on the assessment of airways and respiratory performance represented, respectively, by the letters A and B in the mnemonic rule.

AIRWAY ASSESSMENT

The purpose is to determine whether or not the upper airway is open, and patients are classified as having

free or obstructed airways.[4] Assessment consists of observing thorax and abdomen movement, auscultation of respiratory sounds, and attention to air movement noise and airflow through nose and mouth.[4] The following are considered signs of upper airway obstruction: voice alteration (hoarseness), stridor (usually inspiratory, but it can be biphasic), inspiratory snoring and episodes of labored breathing without breathing noises or perception of airflow through nose and mouth.[4]

BREATHING PERFORMANCE ASSESSMENT

Breathing performance is assessed based on analysis of respiratory rate (RR), respiratory effort, air intake, breathing sounds and pulse oxymetry.[4]

RESPIRATORY RATE AND RESPIRATORY EFFORT

RR must be assessed before handling the child given that anxiety and agitation caused by physical examination can change basal frequency. Adequate RR is inversely related to age (Box 1) and abnormalities are classified as tachypnea (RR faster than normal for the age), hypopnea (RR slower than normal for the age) and apnea (cessation of breathing for 20 seconds or less if accompanied by bradycardia, cyanosis or pallor).[4]

Signs of respiratory effort represent the patient's attempt to compensate for worsened gas exchange by means of increased breathing labor.[3] Presence of several or specific signs of respiratory effort may be related to increased severity of respiratory involvement (Table 1).[6]

AIR INTAKE

Analyzing air intake into the lungs is one of the ways of clinically assessing how the patient is ventilating and is carried out by observing the expansion of the thoracic wall and by auscultation of distal air movement.[4] Reduced thoracic expansion and/or distal air movement can be signs of inadequate ventilation,[6] while asymmetric air intake can be a sign of a unilateral pathological process as atelectasis, pneumothorax, or pleural effusion.[4]

RESPIRATORY SOUNDS AND RESPIRATORY AUSCULTATION

Abnormal respiratory sounds can help diagnose the kind of respiratory problem because these are often associated with certain alterations in the respiratory system (Table 2).

Table 2 - Association between abnormal breath sounds and location of respiratory impairment

Breath sound	Location of Impairment
Stridor and snoring	Obstruction of upper airway (extrathoracic)
Grunting (expiratory grunt)	Lung tissue disease
Gargling	Obstruction of upper airway by secretions
Wheezing	Obstruction of lower airway (intrathoracic)
Stertor (crackling)	Lung tissue disease

Table 1 - Signs of respiratory effort and normal respiratory rate by age

Respiratory effort	Description	Age	Breaths per minute
Nasal flaring	Nostrils flare at each inspiratory movement	< 1 y.o.	30 – 60
Subcostal chest retraction	Retraction of the abdomen, immediately under the rib cage		
Substernal chest retraction	Retraction of the abdomen, under the sternum	1 – 3 y.o.	24 – 40
Intercostal retraction*	Retraction between ribs		
Supraclavicular retraction*	Neck retraction, immediately above the clavicle	4 – 5 y.o.	22 – 34
Suprasternal retraction*	Chest retraction, immediately above the sternum		
Sternal retraction*	Retraction of the sternum, towards the backbone	6 – 12 y.o.	18 – 30
Head bobbing*	Elevation of the chin and frontward extension of the neck in expiration	13 – 18 y.o.	12 – 16
Abdominal respiration*	Retraction of the chest and expansion of the abdomen in inspiration and expansion of the chest and retraction of the abdomen in expiration		

* Signs indicating higher severity of respiratory impairment.

SIGNS IN OTHER ORGANIC SYSTEMS

Alterations in other organic systems can be found in cases of respiratory impairment. Assessment of the circulatory system can reveal the following signs: pallor, cyanosis, cold extremities, tachycardia and bradycardia.[7] Neurological assessment can detect the following states: agitation, anxiety, irritability, and decreased level of consciousness.[7]

PULSE OXYMETRY

Clinical assessment of hypoxemia is not reliable because it depends on many factors, including ambient lighting, skin pigmentation, tissue perfusion and hemoglobin concentration.[8] In optimal conditions, central cyanosis is only found when oxygen saturation (O_2 Sat.) is around 75%.[8] With that in mind, every patient with respiratory distress must have his pulse oxymetry measured.[8]

Pulse oxymetry is measured using a device to estimate hemoglobin O_2 Sat. in arterial blood in a simple, non-invasive, and reliable way.[8] Values of O_2 Sat. ≥ 94% for patients in ambient air often indicate proper oxygenation.[4]

However, it is important to highlight that pulse oxymetry has some limitations.[8] O_2 Sat. may be artificially high when the concentration of carboxyhemoglobin is high (e.g., smoke inhalation), artificially low in the presence of intravenous colorants (e.g., methylene blue) and reduced or increased in high concentrations of methemoglobin.[7] It is also unreliable for patients with decreased tissue perfusion (shock, hypovolemia or hypothermia) because of a weak signal detection.[7] Additionally, it can also fail to measure accurately in the case of patient movement, which can be avoided by checking that the pulse oxymetry measured coincides with the patient's heart rate.[8]

COMPLEMENTARY EXAMS

In addition to specific tests related to the underlying disease compromising the respiratory system, chest radiography and arterial blood gas are complementary tests available in most emergency services that are easy to carry out and can assist in accurately diagnosing respiratory impairment in patients.

Chest radiography is an important tool used to confirm diagnosis of pneumonia, pulmonary edema, pneumothorax or pleural effusion.

Arterial blood gas assesses with precision the extent of hypoxia or hypercabia[7] and helps differentiate between acute and chronic respiratory failure (Table 3).[9]

Table 3 - Blood gas alteration in the differents types of respiratory failure

Respiratiory Failure	pH	pCO_2 (mm Hg)	pO_2 (mm Hg)	HCO_3 (mEq/L)
Acute	↓	↑	↓	normal
Chronic	Normal/ slightly ↓	↑	↓	↑
Acute on Chronic	↓	↑	↓	↑

Reference values: pH=7,4 (7,35 - 7,45); pO_2=80-100 mmHg; pCO_2=35-45 mm Hg; HCO_3=22-26 mEq/L.

CLASSIFICATION

After being assessed through anamnesis, physical examination, and complementary exams (when indicated), patients must be classified according to degree of impairment and type of respiratory problem. Based on a set of clinical signs associated with values of pulse oxymetry or pO_2 and pCO_2 by arterial blood gas test, physicians are able to determine the degree of respiratory impairment (respiratory distress *versus* respiratory failure).

Physicians should look out for signs of severe respiratory failure likely to progress to cardiopulmonary failure, which require immediate intervention to prevent cardiopulmonary arrest: cyanosis; O_2 Sat. < 90% with supplementary O_2 in high concentrations; high number of signs of respiratory effort; bradypnoea; apnea; weak or absent distal movement of air; decreased level of consciousness.[4] Children with severe respiratory impairment can also come into exhaustion, leading to decreased signs of labored breathing. In such cases, diminished effort or lowered respiratory frequency associated with decreased level of consciousness in a child previously considered to have severe respiratory failure, are signs indicating fatigue and impending respiratory arrest.[10]

TYPES OF PROBLEMS OF THE RESPIRATORY SYSTEM

The problems of the respiratory system can be classified into syndromic types according to the location of the disease involved.[4] Respiratory problems

can be classified as: obstruction of the upper airway, obstruction of the lower airway, lung tissue disease, and changes in breathing control. [4]

While certain signs of respiratory distress can occur in most types of respiratory problems (e.g. tachypnea), other signs are often associated with specific types, thus guiding the classification (Table 4). For example, a patient with tachypnea and expiratory wheezing probably has intrathoracic lower airway obstruction as the cause of the respiratory complaint. From the identification of the syndromic type, the next step is to formulate the diagnosis with the aid of an account of present illness and past history.

Table 4 - Signs related to syndromic types of respiratory problems

Upper airway obstruction	Lower airway obstruction	Lung tissue disease	Abnormal breathing control
Increased inspiratory effort	Increased expiratory effort	Expiratory grunt	(tachypnea alternating with bradypnea)
Hoarseness or dry cough	Prolonged expiratory phase	Crackling	Variable breathing effort
Stridor (often inspiratory, buy may be biphasic), snoring and gargling	Wheezing (commonly expiratory, but may be biphasic)	Reduction of vesicular murmur	Artificial respiration
Inadequate chest elevation		Hypoxemia (may be refractory to supplementary oxygen)	Central apnea (apnea with no respiratory effort)
Insufficient air intake by auscultation			

It is important to highlight that although respiratory distress often results from problems in the respiratory system, diseases from other organic systems (such as septic shock and diabetic ketoacidosis) can manifest as respiratory distress, leading to misdiagnosis and inappropriate treatment. Physicians must therefore expand the differential diagnosis to include diseases of other organic systems when a type of respiratory problem fails to be identified or in situations of unexpected responses to the treatment for certain respiratory diseases.

TREATMENT

Management will depend on patient classification in relation to the degree of respiratory impairment and to the kind of respiratory problem. The management of respiratory impairment aims to: a) ensure sustainability and patency of the upper airway, and b) offer support to adequate oxygenation and ventilation.[3] Choice of therapy required depends on the level of impairment. The amount and complexity of the measures adopted increases as the patient's clinical condition worsens (Table 5).[10] The management/treatment for the type of respiratory problem depends on the underlying disease responsible for the clinical picture, and it is not the aim this paper to describe the specific treatments for the large number of diseases that can lead to respiratory problems.

Table 5 - Treatment of respiratory involvement

Respiratory distress
Position of comfort
Airway aspiration, if needed
Oxygen supplentation in concentrations sufficient to keep SaO2 at 94%
Specific therapy based on probable cause
Respiratory failure
Position of comfort
Airway aspiration, if needed
Oxygen supplentation in concentrations sufficient to keep SaO2 at 94%
Assessment to check the need of support ventilation: noninvasive, support ventilation with bag-mask device, invasive
Specific therapy based on probable cause
Cardiopulmonary failure
Chest compression, if indicated
Airway opening
Airway aspiration, if needed
Support ventilation with bag-mask device
Tracheal intubation and mechanic lung ventilation
Specific therapy based on probable cause

AIRWAYS

The first step in the management of respiratory compromise is to ensure upper airway patency and sustainability. The measures used to reach those objectives can be divided into simple and advanced interventions, which are to be indicated according to the conditions of the airway.[4]

Some of the simple interventions commonly used are: placing the child in a comfortable position; head-tilt maneuver by lifting the chin in order to open the airways; jaw-lift maneuver, without extending the head, to be done when cervical spine injury is suspected; nose and oropharynx aspiration; foreign

body removal techniques in conscious patients; adjunct airway devices (e.g., oropharyngeal or Guedel airway).[4] Among more advanced interventions, we can include continuous positive airway pressure (CPAP), noninvasive ventilation (BiPAP), foreign body removal by direct laryngoscopy, cricothyroidotomy, and endotracheal intubation.[4]

OXYGEN DELIVERY SYSTEMS

Supplemental oxygen administration is indicated for patients with confirmed hypoxemia (arterial pO_2 < 60 mmHg or SaO_2 .< 94%) or when there is suspected hypoxemia in an acute situation.[11] The selection of oxygen delivery system depends on the patient's clinical condition and on the fraction of inspired oxygen (FiO_2) necessary to keep $SaO_2 \geq 94\%$.[11] A nasal cannula, for example, may be appropriate for a conscious child with mild respiratory distress requiring supplemental oxygen at low concentrations, but inadequate for a conscious child with severe respiratory impairment requiring supplemental oxygen at high concentrations. For patients unable to maintain spontaneous ventilation, supplemental oxygen should be delivered through a bag-mask device until an advanced airway can be procured.

Oxygen delivery systems can be categorized into high and low flow systems.[11] Low flow systems provide FiO_2 varying according to the patient's inspiratory flow and are classified as variable performance oxygen delivery systems (Table 4).[11,12] High flow systems provide specific inspired oxygen concentration with a flow that meets or exceeds the needs of the patient's inspiratory flow and are classified as fixed performance oxygen delivery systems (Table 6).[11,12]

Table 6 - Devices used for oxygen delivery

Devices*	FiO_2	O_2 Flow
Low Flow Systems		
Nasal cannula	25-40%	1-4 L/min
Simple mask	35-50%	6-10 L/min
Partial rebreathing mask	50-60%	10-12 L/min
Non rebreathing mask	até 95%	10-15 L/min
High Flow Systems		
Venturi mask	25-60%	12-15 L/min
Oxygen hood	25-90%	10-15 L/min

*Humidify the oxygen supply whenever possible to prevent secretion drying in the airways.

A point may be raised for the conceptualization of the non-rebreathing mask as high flow system for children given that in theory these devices deliver a flow that meets or exceeds the needs of a pediatric patient's inspiratory flow. However, according to our point of view, the most important concept on oxygen delivery systems is knowing the FiO_2 provided by each device and the O_2 flow needed for them to work properly.

NONINVASIVE MECHANIC VENTILATION

Noninvasive ventilation (NIV) refers to mechanic respiratory support without endotracheal intubation,[13] and *continuous positive airway pressure* (CPAP) and *bilevel positive airway pressure* (BiPAP) are the main methods used.[14]

It can be indicated in cases when the ARF is reversible within a relatively short period of time.[14] In that scenario, the objective is to maximize lung function until it is possible to revert the precipitating cause. The goal of this ventilatory support is to "buy time" by reducing the load on the respiratory muscles by increasing ventilation, reducing the patient's respiratory effort and improving gas exchange[14] before exhaustion occurs.

Because it does not require endotracheal intubation, NIV avoids some of the risks related to the use of invasive mechanic ventilation, including upper airway trauma, larynx edema, post-extubation vocal cord dysfunction, nosocomial infection, as well as the use of sedatives and neuromuscular blocking agents.[13,14]

High-quality evidence in the literature support the use of NIV for the treatment of ARF in adults in cases of exacerbation of chronic obstructive pulmonary disease and acute cardiogenic pulmonary edema. However, there are few reports of its use with children.[14] To date, case series constitute most of what is known for this age group, with studies showing the effectiveness of NIV in patients with pneumonia, pulmonary edema, cystic fibrosis, bronchiolitis, acute asthma, and acute chest syndrome.[13]

Considering that a number of questions about the use of NIV in Pediatrics have not yet been answered, including which patients can benefit from it (by type of disease) and the right moment for introducing its use, it is not possible to give guidance based on high quality evidence on the pediatric use of this alternative method of respiratory support.[14]

In recent years, the use of high flow nasal cannula has received attention as an alternative mode of respiratory support in pediatric patients. Unlike standard

nasal cannula systems, these devices provide heated and humidified gas at high flow rates (between six and 30 liters per minute).[15]

The mechanisms of action of this ventilatory modality are not yet fully established, but its ability to generate positive airway pressure and meet the patient's inspiratory demands while washing nasopharyngeal dead space are some of the factors highlighted.[15] Although there are theoretical advantages over the standard nasal cannula and face masks, current evidence does not demonstrate equivalence or superiority over other modes of noninvasive ventilatory support as CPAP or BiPAP. [15]

ENDOTRACHEAL INTUBATION AND INVASIVE MECHANICAL VENTILATION

The indication of endotracheal intubation and invasive mechanical ventilation (IMV) in acute respiratory failure is based on the identification of progressive or projected deterioration of respiratory impairment, despite the optimization of therapy indicated for the type of respiratory problem.[3] In this context, three situations suggest indication: inability to maintain adequate oxygenation and ventilation; inability to keep clear and/or protect the airway; potential for clinical deterioration (e.g., epiglottitis or thermal injury of the upper airway by smoke inhalation/burns).

It is important to highlight that although SaO_2, pO_2 and pCO_2 monitoring in patients with respiratory impairment is suggested for the theoretical indication of intubation and IMV in patients with $pO_2 < 60$ mmHg receiving $FiO_2 \geq 0,6$ and/or a pH < 7,2 due to pCO_2 increase (unresponsive to the therapeutic measures taken),[2] the procedure must not be delayed in patients with clinical signs of deterioration with the purpose of obtaining such measurements.

CONCLUSION

Unrecognized acute respiratory failure is the main cause of cardiac arrest in the pediatric population. This is why early recognition and adequate treatment of this condition should be regarded as essential skills for all physicians dealing with this age group.

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