

Evaluation And Quantification Of Respiratory Distress In Children With Asthma

Michael O. Gayle, M.D. and Niranjan Kissoon, M.D.

Introduction

Asthma rates have doubled in the United States during the past 20 years despite better understanding of asthma's genetics, pathogenesis, and new treatments.¹ Older children and adults had lesser increases, but rising rates were found in all age groups, all surveyed races, and both genders. There has been an increase in hospitalization rates of children with asthma as well as an increase in childhood deaths from this disease.² A critical review of the events surrounding deaths from asthma suggests that underestimation of the disease severity by both the patient and physician,³ and a lack of aggressive therapy for acute episodes are also significant contributors.⁴ It is therefore critical that the child with acute asthma be accurately assessed as to the severity of respiratory distress so that a rational and appropriate treatment plan can be formulated. This article addresses pertinent issues in assessment including historical factors as well as the physical examination and ancillary laboratory investigations.

Medical History

Features of previous acute asthmatic attacks can be helpful in identifying children at risk for acute decompensation (Table 1). For instance, it is likely that close observation and early aggressive therapy will be necessary if previous attacks exhibited similar symptoms and progression but required intensive care admission. Children who have had life-threatening asthma attacks usually have a history of monosyllabic speech, history of intubation and mechanical ventilation, nighttime wheezing and rapid progression of attacks.⁴ The time frame over which attacks develop, particularly if they have occurred over a prolonged period, may indicate the development of significant airway inflammation. The intensity of the symptoms can be gauged from the effects they have on exercise, sleep and

other normal activities. Interruption of exercise may not be of major clinical significance; however, loss of sleep indicates clinically relevant airway compromise. Overuse of beta-agonists for symptomatic relief may indicate a severe attack (perceived or real) or an attack refractory to conventional therapy. Alternatively, it may be a clue to the presence of complications such as air leak syndromes or pneumonia. Information such as duration of attack and specific triggering factors also should be sought. In children, it is quite common for an upper respiratory tract infection to precipitate an attack. Prolonged use of oral steroids or high-dose inhaled steroids is also an indication of severe disease.⁵

Appropriate attention to the medical history, therefore, may assist the treating physician to judge the severity of symptoms and the likely clinical course in a particular child with asthma. Older children should be questioned as to their estimation of severity because patients often have a better appreciation of the degree of their airway obstruction than their physician.⁶ In younger patients, close attention to the history and parental impression is vital for the physician to determine severity.

Although the presence of recurrent episodes of coughing and wheezing in childhood signifies asthma, other diseases with similar symptoms also should be considered. For example, causes of lower airway obstruction such as congenital malformations of the respiratory, cardiovascular or gastrointestinal systems, foreign bodies in the airway or esophagus, bronchiolitis, cystic fibrosis and immunologic deficiency diseases may involve the lung and mimic asthma. In children in whom the diagnosis is not yet established, the physician should consider other diagnostic possibilities as "All that wheezes is not asthma." In addition, a thorough history and physical examination according to age and clinical state will assist the physician in formulating an age-appropriate differential diagnosis.

Table 1. Historical Factors Placing A Patient At High Risk For Life-Threatening Asthma

- Previous severe asthma (respiratory failure requiring intubation, hypoxic seizures);
- Frequent need for hospitalization to control asthma;
- Dependence on corticosteroids (inhaled or oral);
- Non-compliance or abuse of medications;
- Labile asthma with pronounced diurnal airway obstruction;
- Brittle asthma with unexpected rapid deterioration of pulmonary function; and
- Chronic asthma with depressive symptoms and manipulative use of asthma.

Michael O. Gayle, M.D., FRCPC, FAAP, FCCM, is an Associate Professor, Department of Pediatrics, University of Florida Health Science Center / Jacksonville, and Pediatric Intensivist, Nemours Children's Clinic / Jacksonville.
Niranjan Kissoon, M.D., FRCPC, FAAP, FCCM, is Professor and Chief, Division of Pediatric Critical Care Medicine at the University of Florida Health Science Center / Jacksonville.

Physical Examination

Table 2. Normal Respiratory Rates In Childhood

AGE	RATE (Brths/min)
Newborn	30 to 60
Infant (1 - 6 months)	30 to 40
Infant (6 - 12 months)	24 to 30
1 to 4 years	20 to 30
4 to 6 years	20 to 25
6 to 12 years	16 to 20
12 years and older	12 to 16

The appreciation of the variability of respiratory rate and heart rate in relationship to age and clinical state in children is important in the overall assessment of the asthmatic child in respiratory distress (Table 2). The heart rate is initially rapid at birth but gradually decreases as the child approaches adolescence.⁷⁻¹⁰ Sinus tachycardia can result from anxiety, fever, pain, blood loss or any other insult that results in increased sympathomimetic activity. Respiratory distress with or without hypoxia is one of the most common causes of tachycardia in children. The respiratory rate decreases with age and shows its greatest variability in newborns and young infants.¹⁰ Reasons for variability in the respiratory rate are numerous and include anxiety, fear, fever and sepsis. Ideally, the rate should be determined over at least a 1-minute period on a few occasions for the calculation of average values.

The assessment of the child in respiratory distress should be conducted in a calm, efficient manner with the assistance of parents and with minimal intrusion from others. Clinical assessment of the asthmatic child should initially address the adequacy of gas exchange and the degree of respiratory

compromise (Table 3). The patient's asthma medication history, the presence of triggering factors such as pneumonia or complications such as pneumothoraces or pneumomediastinum, should be sought. The major pathophysiological derangement in asthma is hypoxemia, which affects all major organ systems in the body. To prevent or limit the effects of hypoxemia, it is important for the physician to recognize the symptoms and signs of respiratory insufficiency and the need for aggressive immediate treatment. Acute exacerbations of asthma can be classified as mild, moderate or severe based on both clinical and physiological assessment of target organs (Table 4). However recently, the National Asthma Education Program Expert Panel⁵ recommended new severity classifications: mild intermittent, mild persistent, moderate persistent, and severe persistent (Table 5).

Overall Assessment

An initial assessment of the child should include a search for evidence of diaphoresis, pupillary dilation and fear, which are all features of "the fight or flight" adrenergic response to hypoxia. Posture provides a clue as to the degree of comfort of the child and hence infers the degree of respiratory difficulty. The child who is alert and lying comfortably is in minimal difficulty. However, the child who prefers the sitting or tripod position is in moderate to severe difficulty and is attempting to derive maximal diaphragmatic excursion since the diaphragm is approximately 4 cm higher in the supine position.¹¹

Central Nervous System

Of all vital organ systems, the central nervous system is the least tolerant to hypoxia; therefore, evaluation of the central nervous system will provide early signs of impending respiratory failure. Central nervous system assessment in the asthmatic child does not entail a full neurological examination initially, but is limited to assessment of global central nervous system function such as alertness, cooperation and motor activity. The child who is alert, cooperative and active is not compromised to any great degree. However, the child who is restless and irritable, or manifests any signs of confusion, such as inability to recognize parents and has decreased level of consciousness, should be considered to be in respiratory failure. While seizure is an uncommon presenting sign, generalized seizures in an acutely ill asthmatic patient indicate significant central nervous system oxygen deficiency and require aggressive treatment.¹²⁻¹³

Respiratory System

The pattern of breathing, which includes the respiratory rate, rhythm and effort, provides a useful practical tool for assessing the respiratory system. Tachypnea is commonly seen with asthma but also can be seen with metabolic acidosis, fever, agitation or psychological factors. Tachyp-

Table 3. Clinical Evidence Of Compromised Gas Exchange

Evidence for hypercapnia*	Evidence for hypoxemia*
Headache	Dyspnea
Wheezing	Tachycardia
Drowsiness, coma	Confusion
Decreased air entry by auscultation	Hypertension
Sweating	Agitation
Asymmetric air entry by auscultation	Peripheral vasoconstriction
Tachycardia	Restlessness
Excessive work of breathing	Rales by auscultation
Hypertension	Tachypnea
Paradoxical chest wall motion	Murmur by auscultation
Peripheral vasodilation	Retractions
Paradoxical abdominal wall motion	Dysrhythmias
Stridor	Nasal flaring
Apneic episodes	Bradycardia
	Grunting
	Hypotension
	Sweating
	Cyanosis

* In many instances, hypercapnia and hypoxemia coexist and a clear separation based on signs and symptoms is not possible.

Table 4. Assessment Of The Severity Of Acute Asthma

	Mild	Moderate	Severe
HISTORY	Intermittent wheezing On no chronic medications Few hospitalizations	On chronic medications ≤ 2 treatments at home Regular hospitalizations No ICU admissions	On chronic medications ≥ 2 at home ICU admission(s) Intravenous β -agonist Previous ventilations
PHYSICAL EXAMINATION	CNS		
	Absence of CNS signs Speaks in full sentences Minimal use of accessory muscles	Anxious, speaks in phrases or partial sentences Use of accessory muscles	Coma, seizures Speaks only in single words or short phrases Signs of chronic respiratory insufficiency
	Respiratory System		
	No cyanosis in room air Good air entry with wheezes	Cyanosis in 40% oxygen Decreased air entry with wheezes	Cyanosis in 100% oxygen Silent chest
	Cardiovascular System		
	\uparrow HR PP < 10 mmHg	$\uparrow\uparrow$ HR PP 10-20 mmHg	$\uparrow\uparrow\uparrow$ or \downarrow HR PP > 20 mmHg
	PEFR		
	70-90% of predicted or of baseline function	50-70% of predicted or of baseline function	< 50% of predicted or of baseline function
	FEV₁/FVC		
	85%	75%	45%
Pulse Oximetry*			
SaO ₂ > 95%	SaO ₂ > 90-95%	SaO ₂ > 90%	
Blood gases*			
PaO ₂ > 80 PaCO ₂ < 35	\downarrow PaO ₂ (60-80) N or \uparrow (PaCO ₂ < 50)	\downarrow PaO ₂ < 60 \uparrow PaCO ₂ > 50	

Categorization into mild, moderate, or severe respiratory compromise should ideally be based on an overall assessment of the patient and not on a single parameter.

FVC	Forced vital capacity	\uparrow	Increased
FEV ₁	Forced expiratory volume 1 s	\downarrow	Decreased
PEFR	Peak expiratory flow rate	HR	Heart rate
x	At sea level in room air	PP	Pulsus paradoxus
N	Normal		

Table 5. Severity Classification Of Asthma By History/Pft/Medication History

Asthma Severity	Symptoms	Lung Function	Medication
Step 1: Mild intermittent	Present during day < 2x/wk; at night < 2x/mo; asymptomatic between exacerbations; exacerbations brief	FEV ₁ > 80% predicted	Short-acting β -agonists as needed
Step 2: Mild persistent	Present during day > 2 x/wk but < 1 time/d; at night > 2x/mo; may affect activity	FEV ₁ > 80% predicted PEF variability 20%-30%	Short-acting β -agonist prn; inhaled anti-inflammatory (sustained-release theophylline or a leukotriene modifier may be considered as alternative)
Step 3: Moderate persistent	Present daily; daily use of inhaled β -agonists; affects activity; exacerbations > 2x/wk	FEV ₁ 60% but < 80% predicted; PEF variability > 30%	Short-acting β -agonist prn; medium dose inhaled GC or low dose inhaled GC + long-acting β -agonist or theophylline
Step 4: Severe persistent	Continual symptoms; limited physical activity; frequent exacerbations	FEV ₁ < 60% predicted	Short-acting β -agonist prn; high dose inhaled GC and long-acting β -agonist or theophylline and oral GC

Adapted from the National Education Program Expert Panel¹⁵

FEV = Forced expiratory volume 1 second PEF = Peak expiratory flow
GC = Glucocorticoid PRN = As needed

nea is the expected compensatory response in acute asthma. However, the finding of bradypnea in acute asthma is an ominous sign. Grunting due to decreased lung compliance is common in acute asthma but may be absent in the child who is becoming fatigued. The presence of dyscoordinated breathing (lack of coordination between thoracic and diaphragmatic muscles of respiration) is also a poor sign.¹⁴ In its extreme form, there is failure of synchronization and the chest moves inward during inspiration.

Increased respiratory effort and work of breathing may be evaluated by assessment of accessory muscle use, subcostal and intercostal retractions, nasal flaring, and the rate and depth of respiratory effort. Children in moderate to severe respiratory distress will present in the initial stages with marked accessory muscle activity as well as subcostal and intercostal retractions. Nasal flaring may indicate mild asthma, but use of sternocleidomastoid and other accessory muscles signifies increasing respiratory effort. The older child may be able to communicate the subjective experience of breathing difficulty or dyspnea. The child with moderate asthma may be able to speak in phrases or partial sentences whereas the severely affected asthmatic often can speak in single words or short phrases. Decreased work of breathing in the child with moderate to severe asthma may indicate extreme fatigue and signals decompensation.

Examination of the respiratory system of the asthmatic child includes a complete chest examination to rule out other diagnostic possibilities, inciting or triggering factors and to exclude complications. Performance of percussion will detect hyperresonance in asthma but not if pneumonia or severe atelectasis is present. Palpation of the chest wall will detect the presence of crepitations from surgical emphysema or tracheal deviation due to a pneumothorax. Finally, auscultation may reveal minimal or no breath sounds (silent chest) indicative of severe airflow obstruction.

Color

The color of the skin and mucous membranes of the acutely ill asthmatic may be normal, pale or cyanotic depending on severity and other factors. Central cyanosis suggests severe desaturation of hemoglobin but may not be recognized in the presence of anemia, poor perfusion, hypocapnia or poor lighting in the examination room.¹⁵ In addition, the evaluation of cyanosis is subjective.¹⁶ If present, therefore, cyanosis is a useful sign of compromised oxygenation but if absent should not be construed as indicating adequate oxygenation. Fortunately, an objective measure of oxygenation, pulse oximetry, is now widely available.¹⁷

Cardiovascular Status

In the acutely ill asthmatic child, tachycardia is the usual physiologic response. However, a normal heart rate or bradycardia in the presence of hypoxemia signifies severe myocardial oxygen deprivation. Pulsus paradoxus is a valuable clinical tool in assessing the severity of airway obstruction in status asthmaticus.¹⁸ The presence of a pulsus paradoxus > 20 mm Hg is associated with moderate to severe airway obstruction. However, its utility is limited to older children and adults because it is difficult to elicit in the young child. This is usually due to the use of inappropriate sized (too large) blood pressure cuffs or difficulty in auscultation of heart sounds due to noisy breathing in the child. However, in conjunction with the overall clinical status of the patient, frequent pulse oximetry and blood gas determination, pulsus paradoxus may allow for better evaluation of the older child with status asthmaticus.

The physician should be able to have an overall impression of the severity of the child's attack based on the assessment outlined in Table 2. In many cases, and especially in acute severe asthma, treatment and evaluation may occur concurrently. In addition, therapy for severe acute asthma should not be withheld pending laboratory evaluation.

Laboratory Evaluation

Pulmonary Function Testing

Rapid assessment of respiratory compromise may be obtained by assessment of pulmonary function (forced expiratory volume in 1 second [FEV₁]) and peak expiratory flow rate (PEFR) in children.¹⁹ Peak expiratory flow rate is the greatest flow that can be obtained during a forced expiration starting from full inflation of the lung (i.e., total lung capacity). Peak expiratory flow rate assessment is an excellent tool for monitoring the severity of respiratory insufficiency as well as for following the progress of children with lower airways obstruction. The procedure is simple to perform using a hand-held spirometer²⁰ and is endorsed by the National Asthma Education program.⁵ Peak expiratory flow rate assessment can be done by the cooperative and trained patient, pediatrician, emergency

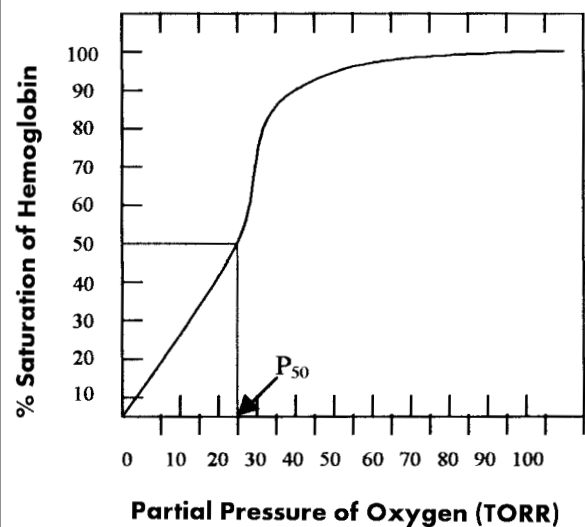
physician or nurse. As this test is effort-dependent, the usefulness, accuracy and reliability of the results (especially in the pediatric age group) relies heavily on close supervision of performance. A peak expiratory flow meter or a mini FEV₁ meter can be used to measure PEFR and FEV₁ in children capable of utilizing these devices (usually older than 5 years of age).

Pulse Oximetry

Pulse oximetry is a noninvasive method of measuring circulating oxygen (i.e., arterial oxygen saturation) and can be used either on an intermittent basis or continuously.¹⁷ This monitor has the advantage of noninvasiveness and does not require calibration before use. It also provides continuous readings and no frequent changes of sites are required. However, the disadvantage of pulse oximetry is that it does not reflect decreasing PaO₂ until the PaO₂ is approximately < 80 mm Hg (Figure 1). For patients with TS_aO₂ < 75% to 80%, oxygenation values often are not an accurate reflection of arterial blood gases. In addition, the accuracy of oximetry can be affected by patient movement, compression of the sensor on the oximeter, low perfusion states, abnormal hemoglobin, (methemoglobinemia), nail polish and infrared heat lamps.¹⁷

For patients at sea level, a mild asthmatic patient will have a TS_aO₂ > 95%, a moderate asthmatic 91% to 95%, and a severe asthmatic < 91%. The clinical usefulness of the pulse oximeter in children with acute asthma was demonstrated by Geelhoed et al.²² They conducted a study on 280 children with a history of asthma who presented to an urban emergency department with wheezing. The aim of the study was to evaluate the initial measurement of arterial

Figure 1. Oxygen hemoglobin dissociation curve demonstrating its sigmoid nature. Partial pressures >65 torr are associated with >95% saturation.



saturation (using a pulse oximeter) as a predictor of outcome in acute childhood asthma compared with other factors of past and present asthma history. They concluded that the initial level of arterial saturation reflects severity as it predicts the likelihood of "poor outcome." Poor outcome was defined as hospital admission or a second visit to the emergency department with ongoing symptoms for those discharged from the emergency department. While there was no absolute cutoff value, a $TS_aO_2 < 91\%$ was likely to result in admission or a second emergency visit.²²

The usefulness of oxygen saturation in combination with peak expiratory flow (PEF) in the management of children with acute asthma, was evaluated in an emergency department.³³ In this study on one hundred twenty-three children with previously diagnosed asthma, the authors concluded that TS_aO_2 and PEF can satisfactorily assess the severity of acute asthma in children and that their initial values can predict the patient's outcome. Pulse oximetry is widely available and should be used in all cases to judge oxygenation during acute asthma therapy.

Arterial Blood Gases

The arterial blood gas is useful and provides objective evidence of pulmonary gas exchange impairment, i.e., oxygen saturation and carbon dioxide ($PaCO_2$). However, its utility in the young asthmatic is limited since sampling may be difficult. In addition, the pain and anxiety associated with attempts at obtaining arterial gases may cause further deterioration in clinical status. A typical arterial gas during an acute uncomplicated asthma attack reveals normal PaO_2 , low $PaCO_2$ and respiratory alkalosis. Hypoxemia in a PaO_2 range of 60 to 80 mm Hg frequently is found even in moderately severe asthma.²⁴ However, a $PaO_2 < 60$ mm Hg may indicate severe disease.

Hypoxemia is due to ventilation perfusion mismatching, whereas low $PaCO_2$ is a result of hyperventilation.²⁵ A progressive increase in $PaCO_2$ is an early warning sign of severe airway obstruction in a child with respiratory muscle fatigue. Arterial pH is an indicator of the overall balance between metabolic demand and respiratory compensation. Hypercapnia and metabolic acidosis despite aggressive medical treatment indicate severe illness and may support the provision of an artificial airway and mechanical ventilation. However, in assessing the acute asthmatic child, serial measurements of $PaCO_2$, PaO_2 and pH are more useful in following response to treatment rather than a single measurement. If multiple samples are contemplated, insertion of an indwelling arterial cannula would be preferable.

Clinical circumstances may arise in infants and small children when a blood gas estimation is desirable but arterial sampling is difficult or impractical. In a well-perfused infant, arterialized capillary blood will show a consistent correlation with arterial PCO_2 and pH and will

reflect a minimal arterial PO_2 value. This technique is performed after warming a highly vascularized capillary bed (earlobe, heel, great toe or finger) for 10 minutes and then making a deep puncture with a scalpel or specially designed lancing blade and then collecting free flowing blood in a heparinized capillary tube.²⁶ The role of arterial blood gases in the emergency management of the acutely ill asthmatic would depend on several factors, of which the most important is the ease of sampling. The insertion of an indwelling arterial cannula greatly facilitates its utility.

Radiology

Chest radiographs are not routinely required in a child with mild and uncomplicated asthma. However, they should be obtained in every child with moderate to severe asthma to define the extent of any associated parenchymal disease or complications, and to differentiate other disease entities, e.g., foreign bodies. A chest radiographic examination often is performed in the assessment of the acute asthmatic patient to examine for evidence of infection or the complications of hyperinflation (pneumothorax or pneumomediastinum) or in those not responding adequately or appropriately to therapy; however, there are no objective data to support this routinely.

Findley and Sahn²⁷ reviewed radiographic films from 90 episodes of acute asthma in adults. The results of this prospective study were that 55 (59%) films were reported as normal, 33 (35%) showed hyperinflation, and 6 (6%) showed minimal interstitial tissue abnormalities that were unchanged from previous films. Although these data would support the policy of not routinely performing chest radiographic examinations in the assessment of acute asthma, this was an adult study and may not necessarily be applicable to children. However, radiographs always should be considered in suspected foreign body aspirations, pneumothorax and pneumomediastinum, as well as in children with moderate to severe attacks requiring hospital admission or in patients not responding appropriately to therapy. The presence of pneumomediastinum, severe hyperinflation, pneumonia or atelectasis is indicative of severity of disease.²⁸

Electrocardiogram

An electrocardiogram is not routinely performed in patients with acute asthma unless cardiovascular symptoms or signs indicate myocardial compromise, insults or abnormalities. Apart from sinus tachycardia, which is usually present in mild to moderate asthma, electrocardiographic findings in severe asthma episodes include P pulmonale, right ventricular strain, right bundle branch block and right axis deviation.²⁹ Electrocardiographic evaluation is more commonly done and is recommended in patients receiving a combination of high dose aerosolized or intravenous beta-adrenergic agents. Beta-adrenergic agonists, especially in combination, have been well documented to be associated with tachyarrhythmias, myocardial ischemia and death.³⁰⁻³²

Table 8. Common Pitfalls In Assessment Of The Asthmatic Child

- Taking improper or inadequate history of previous attacks
- Failure to recognize persistent cough as a sign of bronchospasm
- Unfamiliarity with normal vital signs in children
- Inadequate physical examination of the respiratory system
- Failure to use pulmonary function tests in age-appropriate children
- Over reliance on laboratory data in making treatment decisions

Common Pitfalls In Assessment

The physician unfamiliar with the acutely distressed child with asthma should be cognizant of some of the pitfalls in assessing these children (Table 8). Treatment of the child with asthma can only be given if the severity of the attack in the individual patient is appreciated. An accurate judgment of severity can only be done if the pitfalls outlined are avoided.

Summary

The physician caring for the acutely ill asthmatic child has a wide variety of signs and systems to assist in assessment. An assessment of the severity of the disease should be based on the medical history, and signs and symptoms due to hypoxia on various target organs. Laboratory evaluation, while helpful, has limited applicability in the young child but should be used as an adjunct to clinical assessment where necessary. Based on the history, physical examination and laboratory assessment (when appropriate), acute asthma symptoms should be categorized as mild, moderate or severe. Treatment then can be tailored to disease severity.^{12,43-45}

REFERENCES

1. Cookson WOCM, Moffatt MF. Asthma: an epidemic in the absence of infection? *Science*. 1997; 275:41-44.
2. Asthma Mortality and hospitalization among children and young adults. *Morbidity and Mortality Weekly Report*. U.S. Department of Health and Human Services. CDC. 1998; 45:350-352.
3. Jaimovich D, Kecskes SA. Management of reactive airway disease. *Crit Care Clin*. 1992;8:147-162.
4. Strunk RC. Identification of the fatality-prone subject with asthma. *J Allergy Clin Immunol*. 1989; 83:477-485.
5. National Institutes of Health. National Asthma Education and Prevention Program. *Expert Panel Report 2: Guidelines for the Diagnosis and Management of Asthma*. Bethesda: National Heart, Lung and Blood Institute; 1997: NIH publication No. 97-51A.
6. Ben-Noun L. Severity of asthma: parent's assessment versus the physicians. *Practitioner*. 1990; 233:1052.
7. Furman RA, Halloran WR. Electrocardiograms in the first 2 months of life. *J Pediatr*. 1951;39:307-319.
8. Tudbury PB, Atkinson DW. Electrocardiograms of 100 normal infants and young children. *J Pediatr*. 1950;36:466-481.
9. Alimurung MM, Joseph LG, Nadas AS, et al. The Unipolar precordial and extremity electrocardiogram in normal infants and children. *Circulation*. 1951;4:420-429.
20. Iliff A, Lee VA. Pulse rate, respiratory rate and body temperature in children between 2 months and 18 years of age. *Child Dev*. 1952;23:237-245.
21. Wade OL, Gilson JC. Effect of posture on diaphragmatic movement and vital capacity in normal subjects. *Thorax*. 1951;6:103-126.
22. Nellhouse G, Neuman I, Ellis E, et al. Asthma and seizures in children. *Pediatr Clin North Am*. 1975;22:89-100.
23. Newcomb RW, Akhter J. Respiratory failure from asthma: a marker for children with high morbidity and mortality. *Am J Dis Child*. 1988; 142: 1041-1044.
24. Cohen NH, Eigen H, Shaughnessy TE. Status asthmaticus. *Crit Care Clin*. 1997; 13: 459-476
25. Nowak RM, Tomlanovich MC, Sarkar DD, et al. Arterial blood gasses and pulmonary function testing in acute bronchial asthma predicting patient outcomes. *JAMA*. 1983; 249:2043-2046.
26. Stephen CR, Slater HM, Johnson AL, Sekelj P. The oximeter – a technical aid for the anesthesiologist. *Anesthesiology*. 1951;12:541-555.
27. Tremper KK, Barker SJ. Pulse oximetry. *Anesthesiology*. 1989;70:98-108.
28. Wright RO, Steele DW, Santucci KA, et al. Continuous, noninvasive measurement of pulsus paradoxus in patients with acute asthma. *Arch Pediatr Adolesc Med*. 1996; 150:914-918.
29. Lemen RJ. Pulmonary function testing in the office, clinic and home. In: Chernick V, ed. *Disorders of the Respiratory Tract in Children*. 5th ed. Philadelphia, Pa: WB Saunders Co; 1990:147-174.
30. Lorrie Yoos H, McMullen A. Symptom monitoring in childhood asthma: How to use a peak flow meter. *Pediatr Ann*. 1999;28:31-39
31. Lemen RJ. Pulmonary function testing in the office, clinic and home. In: Chernick V, ed. *Disorders of the Respiratory Tract in Children*. 5th Ed. Philadelphia, PA: WB Saunders Co. 1990: 147-174.
32. Geelhoed GC, Landau LI, LeSouër PN. Evaluation of SaO₂ as a predictor of outcome in 280 children presenting with acute asthma. *Ann Emerg Med*. 1994; 23:1236-1241.
33. Benito Fernandez J, Mintegui Raso S, Sanchez Echaniz J et al. Usefulness of oxygen saturation and peak expiratory flow in the management of acute asthma. *Ann Esp Pediatr*. 1996;45:361-364.
34. Hargreave FE, Colovich J, Newhouse MT. The assessment and treatment of asthma: a conference report. *J Allergy Clin Immunol*. 1990 ;85(b):1098-1111.
35. West JB. Ventilation-perfusion relationships. *Am Rev Respir Dis*. 1977; 116: 919-923.
36. Shapiro BA, Harrison RA, Cane RD, et al. Guidelines for obtaining blood gas samples. In: Shapiro BA, ed. *Clinical Application of Blood Gases*. 4th ed. Chicago, Ill: Year Book Medical Publisher Inc; 1959:248-264.
37. Findley LJ, Sahn S. The value of chest roentgenograms in acute asthma in adults. *Chest*. 1981;80:535-536.
38. Stack AM, Caputo GL. Pneumomediastinum in childhood asthma. *Pediatr Emerg Care*. 1996;12:98-101.
39. Siegler D. Reversible electrocardiographic changes in severe acute asthma. *Thorax*. 1977;32:328-332.
40. Spitzer WO, Suissa S, Ernst R, et al. The use of β-agonists and the risk of death and near death from asthma. *N Engl J Med*. 1992;326:501-506.
41. Sly RM. Adverse effects and complications of treatments with beta-adrenergic agonist drugs. *J Allergy Clin Immunol*. 1985;75:443-449.
42. Crane J, Burgess C, Beasley R. Cardiovascular and hypokalemic effects of inhaled salbutamol, fenoterol, and isoprenaline. *Thorax*. 1989;44:136-140.
43. Alarino AJ, Mansell A, Mansell C. Management of acute asthma in the pediatric office. *Pediatr Ann*. 1999;28:19-28.
44. DeNicola LK, Monem GF, Gayle MO, Kisson N. Treatment of critical status asthmaticus in children. *Pediatr Clin North Am*. 1994;41:1293-1324.
45. Pirie J, Cox P, Johnson D, Schuh S. Changes in treatment and outcomes of children receiving care in the intensive care unit for severe acute asthma. *Pediatr Emerg Care* 1998;14:104-108.