Chapter 28

Asthma: Multisystem Implications

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Nearly one in ten children in the United States has a diagnosis of asthma (CDC, 2004). This frequency has been increasing for decades (Sunyer et al., 1999; Kaiser, 2004) both here and abroad for reasons that are not yet clearly understood (Frischer et al., 1993; Taggart & Fulwood, 1993; von Mutius et al., 1993; Krishnamoorthy et al., 1994; Kussin & Fulkerson, 1995; Schaubel et al., 1996; Meza & Gershwin, 1997; Bruce, 1998; Evans et al., 1998; Strachan & Cook, 1998; Kennedy, 1999; Patterson & Harding 1999; Hartert & Peebles, 2000; Pianosi & Fisk 2000; Doyle et al., 2001; Kaiser, 2004; Malo et al., 2004; Zmirou et al., 2004). According to the Centers for Disease Control and Prevention (CDC) in the United States, from 1979 to 1995, the incidence of asthma increased over 160% for children ages 0 to 4 years and 74% for children ages 5 to 14 years. Similarly, morbidity rate increased 63% for children ages 0 to 4 years and 20% for children ages 5 to 14 years (according to physician office visits for asthma), and mortality rate increased 12% for children ages 0 to 4 years and 146% for children ages 5 to 14 years in that same time interval (CDC, 1998). Follow-up data in a CDC 2002 report indicates that some of these morbidity and mortality figures may have peaked in the mid-1990's (CDC, 2002).

Pragmatically, the incidence figures mean that nearly 10% of all children seen by pediatric physical therapists may have asthma. Does this disease impact a child's motor performance? If so, what kind of impact does it have and what clinical implications does the presence of asthma have for the physical therapist treating pediatric patients?

The purpose of this chapter is to achieve the following:

1. Define asthma and discuss the medical ramifications of the disease.
2. Demonstrate the process of a differential physical therapy diagnosis for potential physical and activity limitations secondary to asthma through the illustration of a clinical case.
3. Identify the types of cardiopulmonary, neuromuscular, musculoskeletal, integumentary, and gastrointestinal impairments that may be associated with this diagnosis.
4. Present possible treatment strategies and specific interventions.
5. Present potential long-term outcomes of physical therapy interventions on the maturation and physical performance of a child with asthma.

PATHOPHYSIOLOGY

Asthma is a pulmonary disease with three significant characteristics: (1) airway obstruction that is reversible either spontaneously or with pharmacologic intervention; (2) airway inflammation; and (3) airway hypersensitivity to stimuli that are classified as either extrinsic or intrinsic (Wagner, 2003; Morris & Perkins, 2004). It is a disease of both the large and the small airways. Complex interactions occur between various cells and cellular elements, resulting in recurrent episodes of shortness of breath, chest tightness, and coughing. Bronchial hypersensitivity to a variety of stimuli is increased (National Heart, Lung and Blood Institute, 1997). These stimuli are classified as extrinsic or intrinsic. Extrinsic or allergic stimuli include pollen, mold, animal dander, cigarette smoke, foods, drugs, and dust. Intrinsic or nonallergic stimuli include viral infections, inhalation of irritating substances, exercise, emotional stress, and environmental factors such as the weather or climate changes. An individual may be sensitive to either type of stimuli or to both types (National Heart, Lung and Blood Institute, 1997).

Researchers have found genetic causes for the development of asthma (Apter & Szefler, 2004; Birkisson et al., 2004), but genetics alone does not account for all types and severities of the expression of the disease (Harik-Khan et al., 2004). The physical, environmental, neurogenic, chemical, and pharmacologic factors that are associated with asthma are specific to each individual. They stimulate or trigger the immune system to release chemical mediators, which in turn cause constriction of the bronchial muscles, increased mucus production, and swelling of the mucous membranes. These effects result in increased resistance to airflow, increasing the work of breathing and decreasing pulmonary ventilation. Mucus accumulation, which has been shown to be abnormal in asthma, may cause blockage of the airways, resulting in further air trapping, hyperinflation, and, eventually, atelectasis (Kurashima et al., 1992). In fact, airway obstruction from mucous plugs has been identified as a primary cause of death associated with asthma (Kuyper et al., 2003). In some patients, there is hypertrophy of the smooth muscles of the airways with new vessel formation, an increase in the number of goblet cells, and deposition of interstitial collagen, which may not be reversible and results in fibrosis of the basement membrane (National Heart, Lung and Blood Institute, 1997). In the acute stage, the early recruitment of cells results in inflammation. In the subacute stage, the recruited and activated resident cells result in a more persistent inflammation. Persistent cell damage and ongoing repair result in chronic inflammation.

In addition to the medical manifestation of asthma, numerous studies have shown that a diagnosis of asthma in childhood results in recurring, chronic respiratory problems, frequent hospitalizations, poorer growth and development than peers, and endurance impairments, all of which result in an increased number of missed school/work days and limitations on the child's participation in normal childhood activities. (Chryssanthopoulos et al., 1984; Ramazanoglu & Kraemer, 1985; McKenzie & Gandevia, 1986; Taggart & Fulwood, 1993; Chye & Gray, 1995; Schaubel et al., 1996; Meza & Gershwin, 1997; Berhane et al., 2000; Pianosi & Fisk, 2000; Abrams, 2001; Mellinger-Birdsong et al., 2003; CDC, 2004).

PRIMARY IMPAIRMENT

DIAGNOSIS

The diagnosis of asthma is made on the basis of history, physical examination, auscultation and palpation, and pulmonary function tests (PFTs), especially in response to a methacholine challenge (Joseph-Bowen et al., 2004). Wheezing and rhonchi may be detected and may even be present when the child demonstrates no breathing difficulty. Coughing, wheezing, difficulty breathing, and chest tightness may be reported as being worse at night or early in the morning. Hyperexpansion of the thorax, decreased use of the diaphragm with increased use of accessory muscles, postural changes, increased nasal secretions, mucosal swelling, nasal polyps, "allergic shiners" (darkened areas under the eyes), and evidence of an allergic skin condition may be noted on physical examination. During an acute asthma attack, the child may evidence an increased respiratory rate, expiratory grunting, intercostal muscle retractions and nasal flaring, an alteration in the inspiration-expiration ratio, and coughing. In severe cases, a bluish color of the lips and nails may be noted.

Attempts have been made to produce a national classification system for the severity of the disease based on clinical findings, but follow-up studies found those systems to inconsistently reflect the severity of the disease (Baker et al., 2003; Braganza et al., 2003; Powell et al., 2003). In spite of the shortcomings, one of the most common severity classification systems was published by the U.S. National Institutes of Health (NIH) Heart, Lung and Blood Institute in 1997 and the details are listed in Table 28-1. (NIH, 1997) The NIH classification system lists asthma by clinical symptoms as (1) intermittent, (2) mild persistent, (3) moderate persistent, or (4) severe persistent.

TABLE 28-1 Clinical Classification of the Disease Severity of Asthma

CLASSIFICATION	INDICATIONS AND BEHAVIORS
Step 1	Intermittent symptoms occurring less than once a week
Intermittent	Brief exacerbations
	Nocturnal symptoms occurring less than twice a month
	Asymptomatic with normal lung function between exacerbations
	FEV_1 or PEFR rate greater than 80%, with less than 20% variability
Step 2	Symptoms occurring more than once a week but less than once a day
Mild persistent	Exacerbations affect activity and sleep
	Nocturnal symptoms occurring more than twice a month
	FEV_1 or PEFR rate greater than 80% predicted, with variability of 20-30%
Step 3	Daily symptoms
Moderate persistent	Exacerbations affect activity and sleep
	Nocturnal symptoms occurring more than once a week
	FEV_1 or PEFR rate 60-80% of predicted, with variability greater than 30%
Step 4	Continuous symptoms
Severe persistent	Frequent exacerbations
	Frequent nocturnal asthma symptoms
	Physical activities limited by asthma symptoms
	FEV_1 or PEFR rate less than 60%, with variability greater than 30%

Practical Guide for the Diagnosis and Management of Asthma Based on Expert Panel Report 2. NIH Publication No. 97-4053. Bethesda, MD: National Institute of Health, National Heart, Lung and Blood Institute, 1997, p.10; and Morris, M, & Perkins, P. Asthma. e-Medicine, available at http://www.emedicine.com/med/topic177.htm, last updated 5/9/04.

Pulmonary Function Tests

PFTs are performed to determine the location and degree of the respiratory impairment as well as the reversibility of bronchoconstriction following administration of a bronchodilator (methacholine challenge). Test values are compared with predicted values based on age, sex, and height (Cherniack & Cherniack, 1983). PFT measurements may reveal decreases in (1) forced vital capacity (FVC), (2) forced expiration during the first second of FVC (FEV_1), (3) forced expiratory volume compared with forced vital capacity (FEV/FVC), (4) peak expiratory flow rate (PEFR) due to airway obstruction in large or small airways; (5) decreases in forced expiratory flow (FEF) during 25% to 75% of FVC ($FEF_{25\%–75\%}$) due to airway obstruction specifically in small airways; and (6) increases in residual volume (RV) and functional residual capacity (FRC) due to air trapping. Generally, patients with asthma are instructed to monitor their daily pulmonary fluctuations and adjust their medication levels by testing their PEFR with a peak flowmeter. However, recent studies have shown that FEV_1 and midexpiratory $FEF_{25\%–75\%}$ are better indicators of disease status than PEFR (Hansen et al., 2001). Peak flowmeters are cheaper and more readily available in a home environment, so they will probably continue as the home equipment of choice until FEV_1 and $FEF_{25\%–75\%}$ can be readily tested at home.

IMPAIRMENT IN INFANCY AND EARLY CHILDHOOD

A diagnosis of asthma is not typically made until the child is 3 to 6 years of age when numerous episodes of pulmonary problems have been demonstrated and are consistent with asthma (Joseph-Bowen et al., 2004). In the meantime, children may be diagnosed with "reactive airway disease." More objective tests such as PFTs are not possible until the child is around 6 years of age and capable of cooperating and performing the tests. The child diagnosed with asthma at 3 to 6 years old will typically present with a history of episodes of wheezy bronchitis, croup, recurrent upper respiratory tract infections, chronic bronchitis, recurrent pneumonia, difficulty sleeping, or respiratory syncytial virus (RSV) infection. Severe RSV infection in infancy is highly associated with a later diagnosis of asthma. Currently, it is not known if children with asthma have a more severe reaction to the virus or if a severe infection with RSV actually causes asthma to develop later in childhood

(Openshaw et al., 2003; Gern, 2004; Silvestri et al., 2004). In addition to normal childhood illness, complications associated with prematurity and very low birth weight also have a high correlation with a later diagnosis of asthma. Like the RSV, it is not known if prematurity causes asthma or simply makes the infants more predisposed to asthma (Koumbourlis et al., 1996; Evans et al., 1998; Kennedy, 1999). Thus, pediatric physical therapists should pay careful attention to a child's medical history to note a history that may indicate a risk for asthma and consider all the ramifications on that child's health, growth, and development when planning treatment interventions.

IMPAIRMENT IN CHILDHOOD

During childhood, PFT measures become an easy and effective diagnostic tool. Overt wheezing is the major presenting sign. Numerous other childhood problems have been associated with a later diagnosis of asthma including an increased prevalence of chronic or recurrent otitis media with effusion (Fireman, 1988) or gastrointestinal problems such as gastroesophageal reflux disease (GERD) (Eid, 2004; Eid & Morton, 2004). Some children may exhibit respiratory difficulty only after exercise, at night, or in cold air (de Benedictis et al., 1990). Other children may have trouble keeping up with peers or with strenuous exercise. Routine PFT results may be normal; however, the history may indicate that an allergen or exercise challenge test should be performed. The prevalence of exercise-induced bronchospasm (EIB) is 70% to 90% in individuals with documented asthma who have performed an exercise challenge test; however, a positive history of EIB is not always given (Sly, 1986; Voy, 1986).

IMPAIRMENT IN ADOLESCENCE

By adolescence, symptoms often decrease. Even when free of symptoms, however, the adolescent may have significant impairment revealed by PFT measures. Continued decrease in severity and frequency of asthma attacks during adolescence results in the belief that children "outgrow" asthma. Research has not demonstrated this to be true. In a study of 286 subjects at age 28, first studied at age 7 and again at ages 10, 14, and 21, it was found that asthma severity at age 28 was similar to that at age 14 (Kelly et al., 1988).

MEDICAL MANAGEMENT

Episodes of asthma attacks are usually reversible and can be prevented or modified to some degree when the individual-specific triggers have been identified. The frequency, duration, and severity of attacks are highly variable even for the same individual. Acute treatment is aimed at reversing the bronchoconstriction. Bronchodilator medications are administered by inhalation or injection. If the asthma attack is severe and does not respond to bronchodilator medications, the diagnosis of status asthmaticus may be made. This is considered a life-threatening medical emergency (Papiris et al., 2002). Hospitalization will be required to administer medications intravenously, to monitor blood gases, and to administer oxygen.

The goals of long-term management are to prevent chronic and troublesome symptoms, to maintain pulmonary function and physical activity level, to prevent recurrent exacerbations, to minimize the need for emergency room visits or hospitalizations, to provide optimal pharmacotherapy, and to meet the patient's and family's expectations of and satisfaction with asthma care (National Heart, Lung and Blood Institute, 1997). This is accomplished through periodic examination, ongoing monitoring, and education. The patient should be taught to self-monitor asthma symptoms and patterns, response to medications, quality of life, and functional status and to perform and record peak flow readings. A written action plan should be developed and reviewed and revised periodically. This action plan should be shared with school and other personnel who are involved with the child. Some allergens such as cigarette smoke, animal dander, and dust can be handled by environmental control. Desensitization ("allergy shots") may be used for triggers such as pollen or mold. Triggers such as emotional stress may be handled by relaxation exercises and education.

The medical management of asthma is primarily through the use of pharmacologic agents that are either intended for short-term relief or long-term management of the condition. (See Table 28-2 for details of current medications.) They can be ingested or inhaled directly to the airways via a variety of metered dose inhalers or nebulizers. Inhaled medications deliver a concentrated dose most effectively with fewer systemic side effects and a shorter onset of action than other means of administration. However, no single delivery system is superior for all patients. The patient's age and compliance, and other factors, such as the type of medication, determine the most effective method (O'Riordan, 2002).

Pharmacologic management is complex and individualized according to the patient's particular needs. Morris and Perkins (2004) of the Brooke Army Medical Center summarized the current intervention strategy as the following:

TABLE 28-2 Current Medications for the Quick Relief and Long-Term Management of Asthma

TYPE OF DRUG	DRUG NAMES AND FUNCTION
Bronchodilators Provide symptomatic relief of bronchospasm due to acute asthma exacerbation (short-acting agents) or long-term control of symptoms (long-acting agents). Also used as the primary medication for prophylaxis of EIA. A metered-dose inhaler can be used for administration.	Albuterol (Ventolin, Proventil) — Beta-agonist for bronchospasm. Relaxes bronchial smooth muscle by action on beta-2 receptors, with little effect on cardiac muscle contractility. Metaproterenol (Alupent, Metaprel) — Beta-2 adrenergic agonist that relaxes bronchial smooth muscle with little effect on heart rate. Salmeterol (Serevent) — Can relieve bronchospasms by relaxing the smooth muscles of the bronchioles in conditions associated with bronchitis, emphysema, asthma, or bronchiectasis. Effect also may facilitate expectoration. Adverse effects are more likely when administered at high doses or more frequent doses than recommended; prevalence of adverse effects is higher. Regular use in patients with EIA associated with smaller decrease in FEV_1 during exercise. Ipratropium (Atrovent) — Decreases vagal tone in the airways through antagonism of muscarinic receptors and inhibition of vagally mediated reflexes. Chemically related to atropine. Has antisecretory properties and, when applied locally, inhibits secretions from serous and seromucous glands lining the nasal mucosa. Only 50% of patients who are asthmatic bronchodilate with ipratropium and, to a lesser degree, with beta-adrenergic agonists. Used primarily in conjunction with beta-agonists for severe exacerbations. No additive or synergistic effects observed with long-term treatment of asthma. Theophylline (Slo-bid, Theo-Dur, Uniphyl) — Mild-to-moderate bronchodilator used as an adjuvant in the treatment of stable asthma and prevention of nocturnal asthma symptoms. Potentiates exogenous catecholamines and stimulates endogenous catecholamine release and diaphragmatic muscular relaxation, which, in turn, stimulates bronchodilation.
Leukotriene receptor antagonists Direct antagonist of mediators responsible for airway inflammation in asthma. Used for prophylaxis of EIA and long-term treatment of asthma as alternative to low doses of inhaled corticosteroids.	Montelukast (Singulair) — Selective and competitive receptor antagonist of leukotriene D4 and E4, components of slow-reacting substance of anaphylaxis. Indicated for treatment of stable, mild, persistent asthma or prophylaxis for EIA. Zafirlukast (Accolate) — Selective and competitive receptor antagonist of leukotriene D4 and E4, components of slow-reacting substance of anaphylaxis. Indicated for treatment of stable, mild, persistent asthma or prophylaxis for EIA.
Corticosteroids Highly potent agents that are the primary drug of choice for treatment of chronic asthma and prevention of acute asthma exacerbations. Numerous inhaled corticosteroids are used for asthma and include beclomethasone (Beclovent, Vanceril), budesonide (Pulmicort Turbuhaler), flunisolide (AeroBid), fluticasone (Flovent), and triamcinolone (Azmacort).	Fluticasone (Flovent) — Alters level of inflammation in airways by inhibiting multiple types of inflammatory cells and decreasing production of cytokines and other mediators involved in the asthmatic response. Triamcinolone (Azmacort) — Alters level of inflammation in airways by inhibiting multiple types of inflammatory cells and decreasing production of cytokines and other mediators involved in the asthmatic response. Beclomethasone (Vanceril, Beclovent, QVAR) — Alters level of inflammation in airways by inhibiting multiple types of inflammatory cells and decreasing production of cytokines and other mediators involved in the asthmatic response.

(continued)

TABLE 28-2 Current Medications for the Quick Relief and Long-Term Management of Asthma—*cont'd*

TYPE OF DRUG	DRUG NAMES AND FUNCTION
	Prednisone (Deltasone, Orasone, Meticorten) —- Systemic steroidal anti-inflammatory medication. Used primarily for moderate-to-severe asthma exacerbations to speed recovery and prevent late-phase response. May be used long term to control severe asthma.
	Budesonide (Pulmicort Turbuhaler, Rhinocort) — Inhibits bronchoconstriction mechanisms, produces direct smooth muscle relaxation, and may decrease number and activity of inflammatory cells, which, in turn, decreases airway hyperresponsiveness.
Mast cell stabilizers Prevent the release of mediators from mast cells that cause airway inflammation and bronchospasm. Indicated for maintenance therapy of mild-to-moderate asthma or prophylaxis for EIA.	Cromolyn (Intal) — Inhibits degranulation of sensitized mast cells following exposure to specific antigens. Attenuates bronchospasm caused by exercise, cold air, aspirin, and environmental pollutants.
	Nedocromil (Tilade) — Inhibits activation and release of mediators of a variety of inflammatory cell types associated with asthma, to include eosinophils, mast cells, neutrophils, and others.
5-Lipoxygenase inhibitors Inhibit the formation of leukotrienes. Leukotrienes activate receptors that may be responsible for events leading to the pathophysiology of asthma, including airway edema, smooth muscle constriction, and altered cellular activity associated with inflammatory reactions.	Zileuton (Zyflo) — Inhibits leukotriene formation, which, in turn, decreases neutrophil and eosinophil migration, neutrophil and monocyte aggregation, leukocyte adhesion, capillary permeability, and smooth muscle contractions.

Adapted from Morris, M, & Perkins, P. Asthma. e-Medicine, available at http://www.emedicine.com/med/topic177.htm, last updated 5/9/04.

Medications used for asthma are generally divided into 2 categories, quick relief (also called reliever medications) and long-term control (also called controller medications). Quick relief medications are used to relieve acute asthma exacerbations and to prevent EIA [exercise-induced asthma] symptoms. These medications include short-acting beta-agonists, anticholinergics (used for severe exacerbations), and systemic corticosteroids, which speed recovery from acute exacerbations. Long-term control medications include inhaled corticosteroids, cromolyn sodium, nedocromil, long-acting beta-agonists, methylxanthines, and leukotriene antagonists. Other medications that have been used to reduce oral systemic corticosteroid dependence include cyclosporine, methotrexate, gold, intravenous immunoglobulin, dapsone, troleandomycin, and hydroxychloroquine. Their use in patients with asthma is extremely limited because of variable responses, adverse effects, and limited experience. Only an asthma specialist should administer these medications. The newest asthma medication is omalizumab (Xolair), a recombinant DNA-derived humanized immunoglobulin G monoclonal antibody that binds selectively to human immunoglobulin E on the surface of mast cells and basophils. The drug reduces mediator release, which promotes an allergic response. Indicated for moderate-to-severe persistent asthma in patients who react to perennial allergens, in whom symptoms are not controlled by inhaled corticosteroids.

Newer drugs are constantly being researched and brought on the market; thus, any listing of medications is relevant only within that timeframe. The overall goal of medication research is to find drugs that will stop the inflammatory process at an earlier point or prevent the presentation of asthma altogether. As the understanding of the pathophysiology and genetics of asthma increases, new medications with more specific but fewer side effects will probably be developed. Physical therapists should check with the physician about current medications.

SECONDARY IMPAIRMENTS

RESTRICTIONS IN DAILY LIFE AND PHYSICAL ACTIVITY

Recurrent asthma attacks may result in secondary physical and medical impairments, eventually causing

the child and the family to place limitations on normal childhood activities. In a study of 1083 children in first through sixth grades, Hessel and colleagues found that 70.5% of the children with asthma had limited their activities for a health reason compared with 6.6% of the children without asthma (Hessel et al., 1996). Asthma may result in the family focusing on the medical needs of the child rather than normal childhood activities. A study by Braback and Kalvesten (1988) found that 32.7% of the children with asthma had missed 2 or more days of school in the preceding month compared with 14.8% of the children without asthma; this finding is replicated in numerous other studies. As the child then approaches adolescence, self-esteem concerns and emotional items such as frustration, anger, and fear of an asthma attack become problems (Townsend et al., 1991). As adulthood is reached, concerns such as choice of vocation and living location become increasingly more important to consider.

Medication Side Effects

Although the medications used in the management of asthma are necessary, the side effects of these medications also may have an impact on daily life. For example, oral corticosteroids may cause an increased appetite and weight gain, fluid retention, increased bruising, and mild elevation of blood pressure. Other side effects reported from a variety of asthma medications are nervousness, headache, trembling, heart palpitations, dizziness or light-headedness, dryness or irritation of the mouth and throat, heartburn, nausea, bad taste in the mouth, restlessness, difficulty concentrating, and insomnia, to mention a few (Morris & Perkins, 2004). To determine if motor, cognitive, or emotional behaviors are related to the medication, consult with the child's physician.

Growth and Development

Another aspect of asthma that is particularly important for self-esteem in adolescence is growth and development. New data contradict the previous belief that children with asthma eventually catch up to their peers in terms of skeletal maturation (Turktas et al., 2001; Allen, 2002; Baum et al., 2002; Wong et al., 2002). For example, Baum and colleagues (2002) found that children with severe asthma have a significantly shorter stature, skeletal retardation, and delayed puberty. Researchers question whether asthma itself or the prolonged use of steroids is responsible for such findings. Long-term studies are needed before definitive conclusions can be reached.

Impact on Financial Costs to the Family and Society

Asthma is associated with the highest related costs of routine pediatric care, reportedly topping $3 billion a year in the United States (Mellon & Parasuraman, 2004). A study of 71,818 children ages 1 to 17 years who were enrolled in a health maintenance organization (Lozano et al., 1997) was conducted to measure the impact of asthma on the use and cost of health care. The children with asthma incurred 88% more costs than children without asthma. Thus, having a child with asthma not only increases the family's focus on their medical needs but also consumes their financial resources. For some families this cost may be at the expense of other needs, placing a financial burden on the family and the community.

SUMMARY OF THE MEDICAL ASPECT OF ASTHMA

Asthma is a common childhood disease that can result in severe functional limitations and restrictions in childhood activities. The disease itself is complex with multiple system interactions such that each child's presentation of asthma is unique. The physical therapist needs to know how this disease affects that particular child's ability to participate in physical activities and what role the therapist can play in optimizing the child's potential for normal development, participation, and health.

PHYSICAL THERAPY EXAMINATION, EVALUATION, AND INTERVENTIONS

Physical therapists are traditionally involved in exercise programs for children with asthma, and studies have shown the efficacy of such programs in improving endurance and decreasing asthmatic symptoms (Cambach et al., 1999; Emtner, 1999; Bing'ol Karako et al., 2000; Ram et al., 2000; van Veldhoven et al., 2001). The specifics of exercise testing and the development of a fitness program are covered in Chapter 8 and will not be covered here. Endurance programs such as treadmill training, which are also common, will not be covered either, as this author prefers to find ways to improve fitness and endurance through participation in typical childhood activities rather than in contrived activities. If physical fitness is

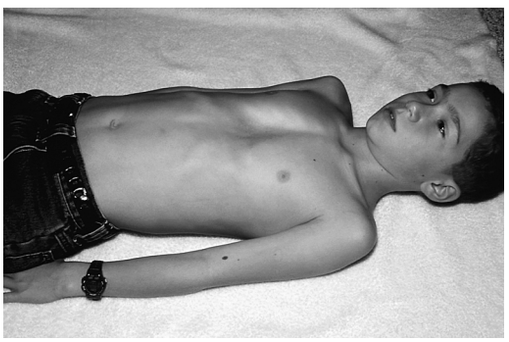
seen as an "exercise duty," it is my experience that the child and family are less likely to follow through, seeing physical exercise as a chore rather than an opportunity for growth. Thus, my intent for the physical therapy section of this chapter is to (1) help the clinician understand the process of a differential diagnosis for the potential physical and activity limitations that may occur in a child secondary to the interaction of asthma with their growing and maturing bodies, and (2) to present strategies and interventions that endeavor to get these children back among their peers, playing and competing in age-appropriate physical activities, rather than participating in adult-supervised exercise programs.

Nevertheless, the child with asthma may need more than a nudge and emotional support to engage in age-appropriate physical activities. Few studies address possible secondary physical impairments, such as adverse musculoskeletal changes/alignments, and neuromuscular recruitment problems that could limit the child's functional potential. (Cserhati et al., 1982, 1984; Fonkalsrud et al., 2000; Holloway & Ram, 2001; Temprado et al., 2002; Roux et al., 2003). In the *Guide to Physical Therapist Practice*, physical therapy is defined as a "profession with ... widespread applications in the restoration, maintenance and promotion of optimal physical function" (American Physical Therapy Association, 2001). Thus, if physical and functional limitations were identified as occurring secondary to asthma, then physical therapy would be the appropriate service to restore, maintain, and promote optimal physical functioning. Physical therapy examinations and evaluation and considerations for physical therapy interventions will be discussed within the context of a single case to illustrate how to perform a differential diagnosis through a multisystem review and how to appropriately plan interventions to address both the medical and physical deficits. Impairment categories listed in the *Guide*, plus an additional category of "internal organs," will be specifically evaluated for their impact on movement potential for the child with asthma (Box 28-1). Long-term outcomes from these interventions will also be presented.

Box 28-1 Motor Impairment Categories

1. Neuromuscular system
2. Musculoskeletal system
3. Integumentary system
4. Cardiovascular/pulmonary system
5. Internal organs, especially gastrointestinal system*

Adapted from American Physical Therapy Association. Guide to Physical Therapist Practice, 2nd ed. Physical Therapy, *81*(1):29, 2001.
*The APTA's impairment categories do not have a category for dysfunction of internal organ systems other than the cardiovascular/pulmonary system; thus "internal organs" was added by this author to correct for this deficit.



◆ **Figure 28-1** Jonathan at age 10 years. Note pectus excavatum (cavus deformity of the lower chest and sternum).

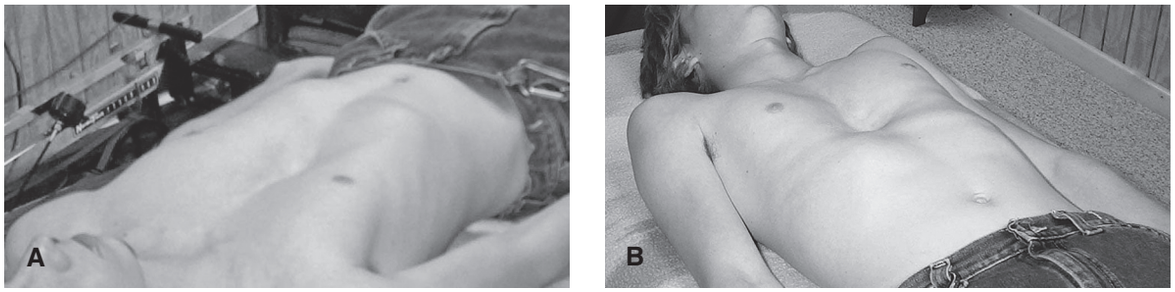
CASE STUDY

MARY MASSERY, PT, DPT

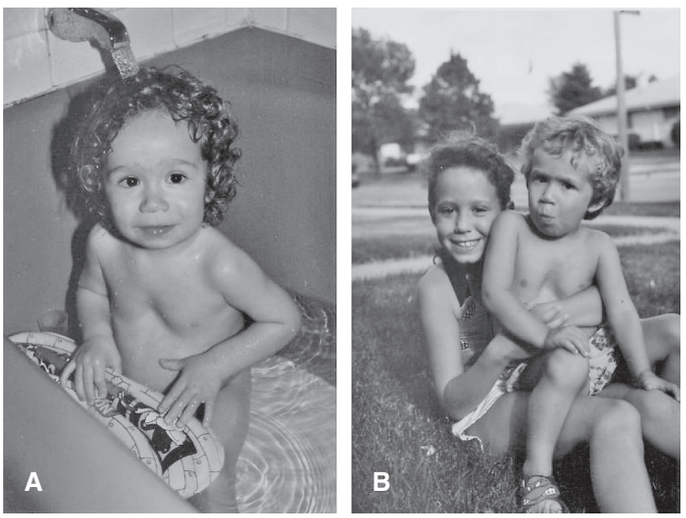
"Jonathan" was referred to physical therapy by his pediatric pulmonologist at 9 years of age. He was in fourth grade and lived with both parents and two older siblings in a large metropolitan area with access to excellent pediatric care. He had two significant diagnoses: exercise-induced asthma (EIA) and a pectus excavatum. Figure 28-1 shows Jonathan at 10 years old.

A pectus excavatum is a skeletal lower chest wall deformity, particularly of the body of the sternum and the surrounding costal cartilage. The cartilage is collapsed inward giving the visual presentation of a hollowing out of the chest, otherwise called a "cavus," "caving-in," or a "funneling" deformity of the lower sternum (Hebra, 2004) (Fig. 28-2). Jonathan's mother reported that his chest "always looked that way" from birth (Fig. 28-3). The thoracic surgeon recommended surgery to correct the deformity, but the family refused any surgical intervention.

Jonathan's mother reported a history of frequent bouts of recurring bronchitis from 3 to 6 years old prior to the eventual diagnosis of asthma at age 6 by a pediatric pulmonologist. He had no history of pneumonia or hospitalizations. Jonathan's asthma has been managed with medications since then, including Flovent twice a



◆ **Figure 28-2** **A**, This 16-year-old male has asthma and a more severe congenital pectus excavatum deformity. **B**, Note lower sternal depression (or funnel), bilateral rib flares, and elevated and protracted shoulders.



◆ **Figure 28-3** Comparison picture of Jonathan at ages 2 and 3 years old. Note the pectus excavatum is more severe at 3 years of age.

day (2 puffs), and Intal and Ventolin as necessary before participation in soccer. In spite of the medications, the patient and his mother reported frequent episodes of extreme EIA symptoms, including chest tightness, wheezing, and shortness of breath after 5 to 10 minutes of soccer, resulting in a termination of the activity. The pulmonary physician reported that Jonathan's PFTs indicated that his pulmonary limitations were minor (i.e., minor peripheral airway resistance). No other significant deficits were found on four different testing dates over a year's time. Cardiac testing was negative. Even on an exercise challenge test by the pulmonologist, Jonathan showed no significant change in lung function, nor a positive response to a bronchodilator challenge. The diagnosis of EIA was made primarily on the basis of the child's clinical presentation rather than PFT results.

If his lung function tests did not show significant impairment from his EIA, and his chest deformity was not causing lung or heart impairments, then what could explain his level of functional limitations? The pulmonologist believed that the medical status of his EIA alone could not have caused such a severe activity limitation. She knew that the patient and his family were motivated to follow his asthma management program especially because Jonathan wanted to qualify for the travel soccer team. As a result, she referred Jonathan to physical therapy to rule out physical impairments that might account for some of the severity of his disease presentation.

PHYSICAL THERAPY EXAMINATION AND EVALUATION

Medical History and Multisystem Screening of the Neuromuscular, Musculoskeletal, Integumentary, Cardiovascular/Pulmonary, and Gastrointestinal Systems

A multisystem approach to screening medical and physical deficits was performed starting with an extensive

medical history, followed by identifying the child's limitations in activities and participation, and then working "backward" with this information to try to uncover the primary impairment(s) that might explain the presenting signs and symptoms. In this case, the pulmonologist had already done an extensive medical history and pertinent tests to rule out other underlying medical pathologies that could account for his participation limitations. Other medical reasons for an increase in asthmatic symptoms could have included GERD, nocturnal asthmatic conditions, pulmonary ciliary dysfunction, or vocal fold dysfunction (Wood et al., 1986; Hayes et al., 1993; Krishnamoorthy et al., 1994; Imam & Halpern, 1995; Elshami & Tino, 1996; Houtmeyers et al., 1999; Patterson & Harding, 1999; Pierce & Worsnop, 1999; Andrianopoulos et al., 2000; Kraft et al., 2001; Roger et al., 2001; Eid, 2004; Malagelada, 2004). Jonathan never had any clinical symptoms of reflux or nocturnal dysfunction, and thus no tests were done. His mother did not recall any testing for ciliary dysfunction (which results in impaired airway secretion motility due to dysfunction of the beating cilia), and the lack of any recurrent respiratory infection, such as repeat pneumonias, made this diagnosis unlikely (Houtmeyers et al., 1999; Cole, 2001). At the time of the physical therapy evaluation, vocal fold dysfunction and supraesophageal manifestations of GERD were not commonly understood to be a possible cause of asthmatic symptoms, and this possibility was thus not explored (Elshami & Tino, 1996; Pierce & Worsnop, 1999; Andrianopoulos et al., 2000; Malagelada, 2004). However, physical therapists currently assessing children with asthma should include gastric and vocal fold disorders as a routine part of the asthma examination.

Screening Assessment of Functional Limitations Related to Asthma

Following a medical history review, the physical therapy examination and evaluation focused on looking at Jonathan's breath support throughout everyday activities to determine if there was a specific area of impairment or a pattern of limitation that could explain his endurance limitations (Table 28-3). Jonathan's functional screening summary is included in Table 28-4. These findings are not unique to Jonathan. In my view, functional breath support screening at age-appropriate levels should be considered a basic examination tool for children with asthma, regardless of the primary reason for the physical therapy referral, in order to identify the contribution that asthma may have to that child's motor performance and health presentation. Functional limitations are identified by behaviors, in this case motor behaviors that require adequate lung volumes and coordinated breath support for optimal performance; thus, they can be assessed through observations and questions to the family about the child's performance. Thus, infants as well as adolescents can be assessed with similar methods.

Breathing: Increased effort was noted with Jonathan's quiet breathing pattern, including (1) occasional paradoxical breathing (i.e., inward movement of the chest or abdomen during inhalation), and (2) frequent forced exhalations. Paradoxical breathing is thought to be due to the significant negative inspiratory pressures that the child with asthma must exert in order to overcome inspiratory resistance in the airways (Han et al., 1993; Massery, 1996). The paradoxical movements of his chest wall indicated a muscle imbalance between the respiratory muscles, usually associated with weak intercostals and abdominal muscles in relation to the diaphragm (Han et al., 1993; Bach & Bianchi, 2003). This weakness in the chest muscles, combined with the unbalanced descent of the diaphragm, may be the result of the pectus excavatum or it may have contributed to the further development of the pectus (the "chicken and the egg" syndrome). On the other hand, Jonathan's forced exhalations were probably secondary to the obstructive lung component of asthma, which constricts the conducting airways during exhalation. This forces the child to recruit expiratory muscles (primarily the abdominals and internal intercostals) to push the air out of the chest even during quiet exhalation, causing increased work of breathing even at rest.

These patterns indicated that Jonathan's motor planning for ventilation muscle recruitment did not appear to be optimal for activities that required greater oxygen consumption because he was already overusing his diaphragm and recruiting his upper accessory muscles at rest, all the while underutilizing his intercostal muscles. All these observations led me to believe that his respiratory muscle imbalance may be significantly contributing to his decreased endurance, and poor musculoskeletal alignment of his chest and overall postural alignment and could account for the endurance limitations not attributed to asthma itself by the pulmonologist.

Coughing: The patient demonstrated an effective cough. The only reports from the family of ineffective coughing or impaired airway clearance strategies during respiratory episodes came from his mother, noting that sometimes when he is sick, his secretions are so thick that they get "stuck" in his chest. Jonathan reported that he rarely drank water at school. This would indicate a need for increased hydration and a possible screening for ciliary dysfunction to rule out the possibility that the cilia themselves were dysfunctional rather than that the mucus

TABLE 28-3 Assessing Functional Limitations Associated with Asthma or Other Ventilatory Dysfunction*

FUNCTIONAL ACTIVITY	SECONDARY PROBLEMS†
Breathing	Inadequate breath support and inefficient trunk muscle recruitment at rest or with activities such that breathing or postural control are compromised
	Asthmatic triggers such as rapid airflow caused by sudden increase in physical activity, dry air or extreme air temperatures, or other triggers that trip an asthmatic reaction
Coughing	Ineffective mobilization and expectoration strategies
Sleeping	Breathing difficulties, signs of obstructive or central sleep disorders
	Nocturnal reflux (GERD)
Eating	Swallowing dysfunction
	Reflux (GERD)
	Dehydration
	Poor nutrition
Talking	Inadequate lung volume and/or inadequate motor control for eccentric and concentric expiratory patterns of speech
	Poor coordination between talking (refined breath support) and moving (postural control)
Moving	Inadequate balance between ventilation and postural demands
	Breath holding with more demanding postures: use of the diaphragm as a primary postural muscle for trunk stabilization
	Inadequate lung volume to support movement
	Inadequate and/or inefficient muscle recruitment patterns for trunk/respiratory muscles causing endurance problems or poor motor performance
	Ineffective pairing of breathing with movement, especially with higher level activities

*The following activities require adequate lung volumes and coordination of breathing with movement for optimal performance.
† These typical secondary problems associated with asthma should be screened for to determine their possible contribution to the child's motor impairment or motor dysfunction.

was simply thicker due to dehydration (Mossberg et al., 1978). He did not report vomiting associated with forceful coughing as many children with asthma report. (Gagging or vomiting is a common occurrence following a hard cough in the pediatric patient, most likely due to the close proximity of the esophagus and trachea, as well as a higher sensitivity in children to noxious stimuli in general [Sontag et al., 2003; Eid & Morton, 2004].)

Sleeping: The patient reported that he sleeps on his back with his arms by his side, and occasionally he sleeps on his side. No breathing difficulties (including apnea, snoring, or irregularities), coughing, or drooling at night were reported that could indicate upper airway obstruction or GERD (D'Ambrosio & Mohsenin, 1998). However, a preference for the supine position at night may indicate a recruitment of upper accessory muscles even while sleeping owing to the optimal length-tension relationship of those muscles in supine along with increased posterior stabilization. Jonathan reports that he does not "curl up" to sleep. It is my clinical observation that children who are primarily upper chest breathers instead of diaphragmatic breathers will often choose to sleep supine with their arms thrown up over their heads rather than prone or curled up on their side, probably because of the improved length-tension relationship of all the anterior and superior chest muscles in supine. They may also report that they start out on their side or stomach, but find themselves on their backs in the morning. Depending on the rest of the findings, one may want to recommend a change in sleep postures for Jonathan, but only if that still allows him to sleep through the night.

Eating: Jonathan did not report problems with chewing or swallowing any foods or textures, nor any difficulties with drinking any type of liquid at any speed. In addition, there was no history of aspiration, choking, or gagging episodes. He did not present with any clinical signs of reflux, which is a common association with asthma and should be ruled out as a contributor to the motor or health restrictions (Sontag et al., 2003).

TABLE 28-4 Synopsis of Jonathan's Initial Physical Therapy Examination and Evaluation

EVALUATION	JONATHAN'S RESULTS
Medical diagnoses (pathology)	Asthma, primarily exercise induced (EIA) Pectus excavatum
Impairment (summary of body functions and structure)	**Cardiopulmonary:** Inflammation and hyperresponsiveness of airways particularly after initiation of exercise with PFTs indicating mild peripheral airway resistance Marked endurance limitations (5–10 minute tolerance) especially with higher level activities (particularly soccer) Occasional dehydration and decreased secretion mobility Increased work of breathing even at rest, RR 20 breaths/min (high end of normal) Auscultation clear in all lung fields No cardiac deficits per cardiologist **Musculoskeletal:** Marked pectus excavatum and elevated sternal angle Rib flares, L > R, with weakness noted in oblique abdominal muscles L > R (patient is right-handed) Functional midthoracic kyphosis of the spine particularly at the level opposite the pectus Decreased lateral side bending, indicating chest wall and quadratus lumborum restrictions Rib cage mobility restrictions greatest in mid chest nearest the pectus Mid trunk "fold" in sitting (rib cage collapsing onto the abdomen in sitting) "Slouched" sitting and standing postures: shoulders protracted and internally rotated Shortened neck musculature, hypertrophy No shoulder range-of-motion limitations **Neuromuscular:** Muscle imbalances in trunk muscles with significantly weaker/underutilized intercostal muscles, oblique abdominal muscles, and scapular adductors Inefficient neuromuscular recruitment patterns for inspiratory and expiratory efforts as well as for postural demands **Integumentary:** No restrictions noted **Internal organs, especially gastrointestinal system:** No reflux, constipation, or other gastrointestinal dysfunction
Functional limitations (breathing, coughing, sleeping, eating, talking, moving)	Breathing pattern was inefficient showing muscle imbalance among the diaphragm, abdominals, intercostals, and upper accessory muscles Movement and participation limitations secondary to medical impairments, endurance impairments, postural impairments, and breath support impairments In addition to movement limitations due to the medical component of asthma, his movements were limited by the simultaneous postural and respiratory demands presented during higher level activities such as soccer and the ventilatory needs to support such tasks No functional breath support limitations noted in sleeping, eating, coughing, or talking activities
Activity and participation limitations	According to mother, Jonathan was beginning to withdraw from participation in physical activities, especially organized athletics, secondary to his "deformed chest" and fear of asthmatic episodes

TABLE 28-4 Synopsis of Jonathan's Initial Physical Therapy Examination and Evaluation—*cont'd*

EVALUATION	JONATHAN'S RESULTS
	EIA caused him to stop playing soccer after typically 5 to 10 minutes
	Patient had already stopped swimming to avoid taking off his shirt among his friends
Diagnosis	9-year-old boy, with history of severe EIA and marked pectus excavatum
	Significant restrictions in chest wall mobility and posture, as well as motor planning deficits, contributed to limitations in adequate breath support, postural control and endurance for desired functional activities and contributed to the continued development of the pectus and other postural deformities
	Dehydration also appeared to play a significant role in triggering a bronchospasm (EIA) during the rapid change in inhalation volume and negative force associated with participation in sports such as soccer
Prognosis	Excellent
	Capable of developing new motor plans
	Musculoskeletal deformities were functional, not fixed; still prepubescent
	Motivated by his desire to "make" the traveling soccer team, and be "normal"
	Supportive family
	Good medical care

Asthma is typically associated with a higher sensitivity or reactivity to dry air in the airway; thus adequate hydration to keep the airway moist (humidity) is necessary to decrease external triggers to asthmatic reactions (Moloney et al., 2002). Hydration is also necessary to keep secretions thin and mobile (Anderson & Holzer, 2000; Moloney et al., 2003). Jonathan did not have a "feeding problem," but he did have a hydration problem, which most likely exacerbated his EIA symptoms.

Talking: Jonathan demonstrated a normal number of syllables per breath (at least 8 to 10) as noted during conversational speech (Hixon, 1991; Deem & Miller, 2000). He was capable of excellent sustained vocalization: 20 seconds (twice the expected length) (Deem & Miller, 2000). He could also talk in all postures at multiple volume levels with good postural control and controlled eccentric breath support. This was clearly the patient's strongest demonstration of breath control within a functional task. I anticipated using this "strength" to reinforce eccentric trunk control and pacing activities with soccer. Speech breathing is primarily eccentric control of the inspiratory muscles; thus I can use his excellent eccentric motor planning for the trunk muscles during speech to recruit the same muscles for eccentric control during other eccentric trunk and postural maneuvers (Deem & Miller, 2000).

Moving: Jonathan reported episodes of extreme shortness of breath (dyspnea) and asthmatic episodes within 5 to 10 minutes of participating in strenuous activities such as soccer. He reported that he "warms up for a minute" before starting to run in soccer. This quick change from rest to running would cause a rapid acceleration in inspiratory volume and flow rates and could possibly trigger his EIA response secondary to upper airway hyperresponsiveness or increased airway resistance (Tecklin, 1994; Milgrom & Taussig, 1999; Anderson & Holzer, 2000; Massie, 2002; Moloney et al., 2002). He also reported that he used his bronchodilator inhaler immediately prior to team practice, which doesn't allow for maximal benefit of the drug; thus incorrect use of medications may also be contributing to his EIA (Physicians' Desk Reference, 2001). It was interesting that Jonathan did not report breathing problems with quiet activities in spite of the fact that his breathing demonstrated inconsistent recruitment patterns and an increased work of breathing at rest. No breath holding was noted with any developmental posture or transitional movement. Discoordination between breathing and movement appear to be contributing to his limitations in higher level activities such as sport participation but not during quiet activities.

Summary of Functional Screening

The functional screening indicated impairment at the level of muscle recruitment for breath support at rest and during strenuous exercise, with resultant endurance impairments. Activities that demanded greater oxygen consumption and faster inspiratory flow rates, such as soccer, immediately used up his pulmonary reserves, causing Jonathan to hit an early "ceiling" effect, forcing him to terminate the activity due to dyspnea and asthmatic symptoms. It also caused a rapid influx of dry air, which most likely triggered the EIA response. No significant problems were noted with functional tasks requiring less oxygen demand and slower inspiratory flow rates such as sleeping, coughing, eating, or talking. In fact, breath support for talking was extremely well developed and was noted as his strongest asset on the functional assessment. Inadequate daily hydration, which would decrease his secretion mobility and produce heightened airway hyperresponsiveness (bronchospasm) was also a significant finding. Jonathan's functional screening results are summarized along with his other examination and evaluation findings in Table 28-4.

ASSESSING THE IMPAIRMENTS RELATED TO FUNCTIONAL LIMITATIONS

When limitations are noted during the functional limitation screening assessment, further impairment testing should be done (age appropriately) to assess the extent of the initial limitations and as a baseline for assessing future progress. A baby or young child would not be capable of performing or cooperating with some tests, such as PFTs, and thus the physical therapist must assess the appropriateness of any impairment test for each specific patient.

According to Jonathan's pulmonologist, his lung pathology alone could not have caused his marked functional limitations noted during athletics such as soccer. Results of our functional screening concur with that opinion, and thus further impairment tests and measures were taken. A summary of the impairment results are found on Table 28-4. A few key findings from his examination will be interpreted here to explain their relevance to his functional limitations.

Jonathan demonstrated a muscle imbalance between his three primary respiratory muscles (diaphragm, abdominals, and intercostals) and his upper accessory muscles of respiration (Primiano, 1982; Cala, 1993; Han et al., 1993). All play a dual role in simultaneously meeting his breathing needs and his postural needs (Hodges & Gandevia, 2000; Gandevia et al., 2002). Because of his asthma, Jonathan had to overcome increased inspiratory resistance even at rest, which forced him to overrecruit the upper accessory muscles from a very young age, setting up a pattern of overuse, which leads to fatigue (endurance factor). When he needed more oxygen during exercise, he recruited those same accessory muscles even more so, reaching a "ceiling" on his respiratory reserves. He had no "extra" muscles to recruit when he needed more oxygen (again with an impact on endurance). Thus, when his postural demands increased, such as during soccer, and his oxygen demands couldn't support these needs, his oxygen requirements limited the activity (Hodges et al., 2001).

Typical of many patients who have an increased work of breathing, Jonathan used his accessory muscles of respiration at the expense of his diaphragm and external intercostals, seen clinically as occasional paradoxical breathing and forced expiratory maneuvers at rest. I suspect this pattern contributed to the sternal abnormalities that formed early in life. In my clinical observations, children with an early onset of asthma who overuse their sternocleidomastoid, scalene, and trapezius muscles cause a greater force on the anterior-superior pull on the sternal angle, resulting in an elevated sternal angle. The manubrium (the top portion of the sternum) is calcified at birth, while the body of the sternum is primarily cartilaginous. Perhaps that is why the solid manubrium tilts superiorly with the pull of the sternocleidomastoid while the less stable sternal body is less likely to be drawn upward.This in turn causes greater *superior* expansion of the chest at a loss of *anterior* chest excursion (decreased circumferential chest wall excursion) leading to chest wall restrictions. In addition, children like Jonathan tend to initiate inspiration with a greater effort to overcome the increased airway resistance from asthma, creating a larger negative inspiratory force (NIF) and more collapsing forces on the chest wall (Han et al., 1993). Clinically, this is observed as an excessive inferior descent of the diaphragm (low abdominal excursion) with flat or paradoxical intercostal movement (inward movement of the mid or lower chest wall). I believe that, over time, the repeated excessive NIF contributed to a decreased developmental stimulus for the activation of the intercostal muscles, thus setting up a pattern of muscle imbalance along Jonathan's chest wall and contributing to the further development of his pectus and associated rib cage and thoracic spine restrictions.

This is a pattern that I see repeated in numerous other cases in which asthma limits the child's participation in normal activities from infancy through puberty. I believe that the neuromuscular recruitment patterns developed early in life due to the child's ventilatory needs result

in musculoskeletal abnormalities and neuromuscular imbalance of the respiratory/postural trunk muscles for movement. This is unique to childhood asthma because of the maturation and development of their systems versus adult-onset asthma where the motor systems have already completed typical development.

Evaluation: Impairments of the Neuromuscular, Musculoskeletal, Integumentary, Cardiovascular/Pulmonary, and Gastrointestinal Systems

1. From a medical perspective, Jonathan's asthma was well managed, but it was still limiting participation in typical childhood activities. Thus, his cardiopulmonary system was not the only system with impairment. Typical secondary medical impairments such as GERD were not present, but daily underhydration was likely a significant contributor to his EIA response (Anderson & Holzer, 2000; Moloney et al., 2002).
2. Jonathan demonstrated muscle imbalance in quiet and strenuous breathing. It appeared that he could benefit from learning new motor strategies to breathe effectively and efficiently (neuromuscular retraining) to attempt to better support ventilatory needs simultaneously with the postural demands of the task.
3. Jonathan demonstrated numerous chest wall and spine restrictions, but no integumentary restrictions. He needed more musculoskeletal mobility in order to support adequate internal lung expansion at low energy cost and decrease the triggers that caused his EIA response, such as rapid inspiratory airflows (Leong et al., 1999; Wilson et al., 1999). This mobility was necessary before neuromuscular retraining could be effectively undertaken, and before adaptive cardiopulmonary strategies could be optimized. Thus, with his asthma well managed from a medical perspective, the *musculoskeletal* system presented the primary obstacles to his optimal physical function and endurance.

Therefore, in spite of the fact that his primary diagnosis was cardiopulmonary, this examination pointed to significant musculoskeletal and neuromuscular impairments associated with Jonathan's medical diagnosis. Yet, the literature rarely mentions this possibility. An extensive search of Medline, Cochrane Reviews, and CINAHL databases showed a plethora of articles identifying endurance impairments, quality of life issues, and poor overall health as consequences of childhood asthma, but only a very few articles identified potential secondary physical impairments such as those observed in Jonathan:

1. Musculoskeletal restrictions and deformities of the chest wall, upper extremity, or spine (Cserhati et al., 1982, 1984; Fonkalsrud et al., 2000).
2. Inefficient neuromuscular recruitment for breathing and postural control (Weiner et al., 2002; Cooper et al., 2003; McConnell & Romer, 2004).
3. Ineffective coordination of breathing with movement (no articles were found on this topic).

Of particular interest, large-scale literature reviews of breathing retraining such as the Cochrane Reviews have been more plentiful in the past few years. Although authors of these reviews continue to conclude that the evidence for strengthening respiratory muscles or neuromuscular retraining of breathing patterns is inconclusive based on a lack of controlled studies or the small number of available controlled studies, they specifically state that that doesn't mean that breathing retraining doesn't work, just that there is not enough hard evidence to make a decision either way (Holloway & Ram, 2001; Steurer-Stey et al., 2002; Ram et al., 2003; Gyorik & Brutsche, 2004; Markham & Wilkinson, 2004).

DIAGNOSIS

Jonathan is a 9-year-old boy with a history of severe EIA and marked pectus excavatum. Significant restrictions in his chest wall mobility and posture, as well as motor planning deficits and underhydration, appear to contribute to limitations in breath support and endurance for his desired functional activities and contribute to the continued development of the pectus excavatum and other postural deformities by perpetuating trunk muscle imbalance and an increased work of breathing.

PROGNOSIS

Jonathan's parents have rejected a surgical option to reduce his pectus and thus his prognosis was related to the potential success of a noninvasive physical therapy program. I believed that Jonathan had an excellent prognosis for the following reasons: (1) he was closely followed from a medical perspective, (2) he was neurologically intact and capable of developing new motor plans, (3) his musculoskeletal deformities were functional, not fixed, and he was still prepubescent, and (4) just as important, Jonathan was extremely *motivated* by his desire to "make" the traveling soccer team and his desire to be able to take his shirt off without embarrassment due to the pectus. His mother was completely committed to helping her son maximize any opportunity to improve his health and well-being, including doing daily exercises at home under her supervision, if necessary. With this high level of support from the patient and his family, I anticipated making maximal progress with about 6 to 12 visits over a 1-year timeframe.

TABLE 28-5 Goals of Physical Therapy Program

PHYSICAL THERAPY GOALS	JONATHAN'S GOALS
Long-term goal	**Reduce secondary impairments** that limit Jonathan's ability to achieved his desired level of physical activity performance and participation (soccer, baseball, swimming, etc.) and health (missed days of school, ER visits, sicknesses)
Short-term goals	**Increase joint mobility** of rib cage and thoracic spine to promote full ROM for optimal breath support, full trunk movements to optimize skilled movements of the trunk musculature, decrease forces promoting developing kyphosis, as well as decrease forces promoting developing pectus excavatum.
	Improve muscle strength and muscle balance between diaphragm, intercostals, abdominals, paraspinals, scapular retractors, and neck muscles to normalize forces on the developing spine (decrease kyphosis), ribs (increase individual rib movement potential), sternum (decrease pectus forces), and shoulder (decrease anterior humeral head positioning and potential shoulder ROM losses).
	Improve motor planning of trunk muscle recruitment for respiration and posture by: Changing the sequence of activation of respiratory muscles to promote sooner activation of intercostal muscles, thus preventing paradoxical chest wall movement, which increases pectus forces (greater negative inspiratory forces reinforce development of a pectus if intercostals are weak, paralyzed, or delayed). Refining the respiratory pattern during quiet and stressful breathing to improve endurance by teaching Jonathon to utilize his diaphragm (endurance muscle) for a greater percentage of the ventilatory workload, and to decrease his over-recruitment of accessory muscles (short burst supporters) during quiet breathing. Refining recruitment pattern of postural muscle to: Increase recruitment of intercostals, oblique abdominal and transverse abdominal muscles, scapular retractors, and paraspinals. Decrease over-recruitment of rectus abdominus and sternocleidomastoid (SCM). Improve core trunk movements so that the intercostals, oblique abdominals, and transverse abdominal muscles become the primary stabilizers of the mid trunk, thus avoiding the SCM being overutilized as the primary trunk flexor, which can cause rib elevation, forward head, and eventually rib flares from underuse of oblique abdominals.
	Improve coordination of breathing with movement to improve oxygen transport during an activity (improving endurance) and to optimize the coordination between the respiration and postural demands of any physical task in order to improve overall physical performance from simple tasks such as activities of daily living to demanding tasks such as soccer.
	Improve patient and family's understanding of how they can more effectively manage the adverse effects of asthma on Jonathan's posture and movement patterns in order to reduce external triggers that precipitate his asthma attacks. This includes improving his overall hydration levels especially during athletic activities, decreasing activities that result in rapid changes in inspiratory airflow demands (slower warm-ups), and improving the timing of his asthma medications with strenuous activities.

PHYSICAL THERAPY INTERVENTIONS AND OUTCOMES

The goals of Jonathan's physical therapy program are listed in detail in Table 28-5, and the physical therapy interventions are summarized in Table 28-6. These represent typical goals and intervention strategies for many children with asthma and can be adapted for any other case or age range.

Asthma (Cardiovascular/Pulmonary and Gastrointestinal) Management Interventions

Jonathan was instructed in immediate changes that he could implement at school, home, and on the soccer field to decrease the triggers that set off his EIA response. He was extremely sensitive to a sudden increase in inspiratory volumes and flow rates that occurred secondary to soccer warm-ups, which started with laps around the

TABLE 28-6 Physical Therapy Interventions

IMPAIRMENT CATEGORY	INTERVENTIONS FOR JONATHAN
Asthma (cardiopulmonary) management strategies	Increased hydration to decrease extrinsic EIA triggers Improved timing of medications with activity level to get maximal benefit of medication Developed and implemented a new warm-up protocol for soccer practices and games that slowly increased his respiratory work load to avoid dramatic changes in inspiratory lung volumes and speed to avoid EIA trigger such as initiating a walk/run warm-up rather than running only, with gradual increase in running time and speed and stretching all trunk musculature prior to soccer Coordinated ventilatory strategies with movement and stretching to Decrease respiratory work load and EIA trigger Improve efficiency of movement with resultant improved endurance Implement breath control techniques to prevent or minimize EIA attacks Improve awareness of oncoming EIA symptoms Use controlled breathing techniques to ward off EIA attack when possible
Musculoskeletal interventions	Rib cage mobilization to increase chest wall and thoracic spine mobility in order to reduce respiratory workload and increase likelihood of recruiting intercostal muscles for more efficient respiration and support for developing thorax (reducing pectus excavatum forces) Intercostal muscle release to optimize length-tension relationship Quadratus lumborum muscle release to promote activation of oblique and transverse abdominis muscles for lower trunk stabilization instead of quadratus Active assistive anterior and axial glides to thoracic spine Home program to maintain newly gained trunk mobility
Neuromuscular interventions	Specific diaphragmatic training from recumbent to upright positions, and eventually to sporting conditions Emphasis on slow, easy effort during initiation of inhalation to prevent overpowering developing intercostal muscles Increased recruitment and strength of intercostals for all breathing patterns, postural control, and skeletal development (reducing pectus, paradoxical breathing, and thoracic kyphosis) Specific coordination of inhalation/exhalation patterns with all activities (ventilatory strategies) Increased recruitment and strength of scapular adductors, shoulder external rotators, and paraspinals for increased posterior stabilization Lengthening of neck accessory muscles through active stretching Midtrunk stabilization exercises (reducing rib flares and improving midtrunk interfacing between intercostals and abdominals)
Integumentary interventions	None needed at this time
Internal organs (gastrointestinal) interventions	Increase hydration, especially during sporting activities

soccer field. It was likely that the combination of (1) the *dryness* in his airway caused by the change from nose breathing to mouth breathing due to the sudden need for increased inspired air during the running activity and (2) the *large, fast moving volume* of air required to perform this high level of exercise played a significant role in triggering an acute attack (Anderson & Holzer, 2000; Moloney et al., 2002). Within 5 to 10 minutes of soccer, he would typically experience such extreme shortness of breath that he was forced to stop playing. Often he did not recover in time to rejoin his teammates.

Jonathan's management program included several steps:

1. Instruction in increasing his hydration overall, and specifically to use hydration before and throughout the games and practices in order to keep his upper airway moist (Anderson & Holzer, 2000; Moloney et al., 2002).
2. He began to take his medications sooner, at least a full 15 to 30 minutes prior to the start of soccer, in order to receive the maximum benefit from the drugs.
3. He started a new warm-up that slowly increased his activity level so that the oxygen demand slowly increased, allowing him to breathe through his nose for a longer period of time and allowing the necessary inspired air volume to also increase slowly.
4. He stretched his trunk, spine, rib cage and shoulders prior to the game to maximize mobility (compliance) of his chest wall movements, thus decreasing his work of breathing.
5. He coordinated his breathing specifically with the relationship of the trunk movement and rib cage during each stretching exercise and movement in general to reinforce normal pattern combinations of movement and breathing (ventilatory strategies) (Massery & Frownfelter, 1996; Temprado et al., 2002).
6. He was taught two particular breath control techniques to help him regain control of breathing during the early stages of an asthmatic attack: (a) repatterning controlled breathing technique and (b) an enhanced Jacobsen's progressive relaxation exercise. The repatterning technique is described by Frownfelter and Dean (1996) in their cardiopulmonary textbook (p. 393):

> The patient is asked to start with exhalation. "Try to blow out easily with your lips pursed. Don't force it just let it come out." Suggesting that the patient visualize a candle with a flame which their exhalation makes flicker but not go out will help to produce a prolonged, easy exhalation. Doing this allows the respiratory rate to decrease automatically. When the patient feels some control of this step, then ask him or her to "hold your breath at the top of inspiration just for a second or two." Make sure the patient does not hold his or her breath and bear down as in a Valsalva maneuver. Last, ask the patient to take a slow breath in, hold it, and let it go out through pursed lips. Patients learn that when they are short of breath, this technique often helps them to gain control, making them feel less panicky.

Jacobsen's modified technique utilizes ventilatory strategies to help the patient experience the difference between inhaling and contracting the upper trapezius versus exhaling and relaxing the trapezius in order to develop new motor plans to keep the trapezius from being over recruited (Massery & Frownfelter, 1996).

Asthma Management Outcomes

Jonathan rigorously followed the regimen including carrying a water bottle with him everywhere, even in the classroom. He noticed an immediate decrease in chest tightness and dyspnea during soccer practice and games. Of particular note, prior to using the repatterning controlled breathing technique, Jonathan said he had no way to stop the progression of his asthma attack once it started. Now, he said that if the attack was mild, he was able to "work through it" with the repatterning and it did not develop into a full-blown attack. He could now play a whole game of soccer without EIA preventing his participation. In fact, he made the travel soccer team and could play four consecutive games of soccer in 1 day without EIA symptoms. As a consequence of decreasing EIA triggers, Jonathan began having fewer and fewer asthmatic attacks, such that all asthma medications were discontinued 2 months after starting physical therapy. This was not an intended consequence of physical therapy, but a welcome one. Jonathan reported only one incident of bronchitis in the following year, and no asthma attacks after 2 months of physical therapy.

Musculoskeletal Interventions

Jonathan needed increased chest wall and spine mobility before attempting neuromuscular training of muscles along that tight rib cage. Manual rib mobilization was performed to all 10 ribs bilaterally (Johnson, 1989) to increase individual rib movement potentials, to increase rib cage compliance, and to increase the potential for axial rotation of his thoracic spine (a tight rib cage makes lateral or axial movements of the thoracic spine less possible). Jonathan was positioned in side lying with a large towel roll placed under his lower ribs to maximize rib expansion on the uppermost side. From the results of my testing, the intervention was focused more on the left side than the right, and more in the midchest than the upper or lower chest. This was followed by intercostal muscle release techniques to maximize intercostal spacing and optimize their length-tension relationship for neuromuscular retraining. Finally, his quadratus lumborum was released bilaterally to allow for more separation between the rib cage and the pelvis. Posteriorly, the thoracic spine was only mildly restricted in anterior glides (extension of spine) and axial rotation, so active assisted mobilizations were incorporated into his home program. Jonathan worked on maintaining his newfound trunk mobility with a home stretching program.

TABLE 28-7 Lateral Trunk Flexion Mobility Test for Rib Cage and Quadratus Lumborum

TEST	INITIAL DATE	DISCHARGE DATE 11 MONTHS LATER	REEVALUATION 4 YEARS AFTER DISCHARGE
Lateral side bend toward L: mobility of right rib cage	2 1/4″	4 1/2″	3 5/8″
Lateral side bend toward L: mobility of right quadratus lumborum	1″	3″	2 3/8″
Lateral side bend toward R: mobility of left rib cage	1 1/2″	3 3/4″	3″
Lateral side bend toward R: mobility of left quadratus lumborum	1 1/4″	2 1/2″	2 3/8″

Note: From initial evaluation to discharge 11 months later, Jonathan's rib cage mobility doubled on the right, and more than doubled on the left. His quadratus lumborum length tripled on the right and doubled on the left. At the 4-year follow up examination, he had lost some mobility at all levels except the left quadratus lumborum.

TABLE 28-8 Other Tests and Measures

TEST	INITIAL DATE	DISCHARGE DATE 11 MONTHS LATER	REEVALUATION 4 YEARS AFTER DISCHARGE
Pectus volume displacement (typical: zero or minimal volume)	34 mL (taken 4 months after initial evaluation)	18 mL	17 mL
Respiratory rate (typical 10 – 20)	20	11	–
Auscultation	Clear	Clear	Clear
Phonation (typical 10 seconds)	20 sec	25.5 sec	28.6 sec
PFTs (pulmonary function tests)	Normal lung volumes and flow rates	Not taken	Normal lung volumes and flow rates

Note that Jonathan's pectus excavatum, which was 34 mL H_2O when measured 4 months into treatment, was reduced by half to 18 mL H_2O at discharge and was maintained relatively at the same level when remeasured 4 years later.

Musculoskeletal Outcomes

Jonathan made tremendous progress in trunk mobility as measured by range of motion in lateral trunk flexion (Table 28-7). His rib cage mobility doubled on the right, and more than doubled on the left. His quadratus lumborum length tripled on the right and doubled on the left. His anterior glides and axial rotation glides of thoracic spine were now normal. His pectus excavatum, which was 34 mL H_2O when measured 4 months into treatment, was reduced by half to 18 mL H_2O at discharge 7 months later (Table 28-8). Even though his pectus volume was not measured until midway through his physical therapy timeline, he still showed a reduction of approximately 50% within 8 months. There was no initial photo to compare his pectus, as the patient was uncomfortable having his picture taken at that time.

Postural assessment showed elimination of functional kyphosis in sitting and standing postures. Jonathan no longer showed a midtrunk "fold" in a sitting posture. Mother and son reported that his teachers no longer continually reminded him to "sit up straight" in school. Inferior rib flares were no longer apparent as his abdominal muscles now adequately stabilized the rib cage at the midtrunk and his primary neuromuscular recruitment pattern now utilized his abdominal muscles instead of his sternocleidomastoid muscles as his primary trunk flexor. His sternal angle elevation appeared slightly reduced but was not objectively measured.

Neuromuscular Interventions

The priorities of Jonathan's physical therapy program were to address his medical needs first, then his musculoskeletal restrictions, and finally his neuromuscular impairments. Jonathan needed to balance the strength and recruitment patterns of his respiratory and postural muscles to optimize breath control at a low energy cost while simultaneously providing appropriate muscle force to his trunk that would promote normalizing forces on his developing spine and rib cage (Han et al., 1993; Hodges & Gandevia, 2000).

Respiration can be achieved through numerous combinations of muscles and activation patterns. The literature shows variability in the percentage of work that the diaphragm does during normal quiet breathing, with the range generally noted from about 60% to 85% of the total muscular effort (Cherniack & Cherniack, 1983; Frownfelter & Dean, 1996). The intercostals, paraspinals, upper accessory muscles, and abdominal muscles supplement the diaphragmatic effort (Primiano, 1982; Saumarez, 1986; Dean & Hobson, 1996). Clinicians have observed, and researchers have confirmed, that the body attempts to recruit the most efficient combination of respiratory muscles for a specific respiratory or motor task in different postures (Wolfson et al., 1992; Nava et al., 1993; Estenne et al., 1998; Wilson et al., 1999; Aliverti et al., 2001; Temprado et al., 2002). Thus, the neuromuscular retraining of Jonathan's respiratory muscles started with specific diaphragmatic training in a side-lying posture to facilitate a more optimal length-tension relationship of the diaphragm while simultaneously facilitating a less optimal length-tension relationship of the upper accessory muscles to minimize their recruitment during quiet breathing. Jonathan did not respond with increased diaphragmatic recruitment and excursion with positioning and verbal cues alone, so manual techniques were added.

Several techniques were used, but the one that produced the greatest consistency, reproducibility, and appropriate timing of activity in the diaphragm was the "diaphragm scoop" technique (see Massery & Frownfelter, 1996). This technique provides specific quick stretch input to the central tendon of the diaphragm via the patient's abdominal viscera at the end of the expiratory cycle in an effort to recruit the central tendon as the initiator of the next inspiratory effort. Continued manual cueing was provided throughout the entire inspiratory phase to facilitate greater inferior excursion of the diaphragm. An emphasis was placed on initiating inspiration with an "easy, slow onset" to avoid recruitment of the upper accessory muscles and an overpowering of his intercostal muscles (paradoxical breathing). Once the patient could consistently succeed in recruiting the diaphragm in side lying, he was challenged by decreasing manual input and increasing postural demands by using positions such as sitting and standing. At this point Jonathan was instructed to practice this technique using "visualization" at home just before sleeping to take advantage of a relaxed state. Eventually, he was trained to use the diaphragm breathing technique in sports as well as static postural holds. Auditory cues for the rate, rhythm, and depth of inspiration were included in all breathing retraining techniques. Objective measures of his success were taken with assessment of chest wall excursion (CWE) (Massery et al., 1997; LaPier et al., 2000).

Jonathan demonstrated poor recruitment of his external intercostal muscles, which are needed to stabilize the chest wall during inspiration to prevent paradoxical breathing and the potential development of a pectus excavatum secondary to this inward movement (Han et al., 1993). Jonathan demonstrated this paradoxical chest wall movement even at rest in his mid rib cage. Thus, weak intercostals could be, in part, responsible for the development of his pectus. I used manual facilitation techniques with (1) upper extremity flexion, abduction, and external rotation activities (D2 diagonals from proprioceptive neuromuscular facilitation [PNF]) (Knott & Voss, 1968); combined with (2) thoracic extension and rotation; intentionally paired with (3) large inspiratory efforts, in order to utilize optimal length-tension relationships and function of the external intercostals; and (4) a maximal inspiratory effort followed by a peak inspiratory hold to increase positive outward pressure on the anterior chest wall (Decramer et al., 1986; Saumarez, 1986; Han et al., 1993; Rimmer et al., 1995; Wilson et al., 2001; Temprado et al., 2002). Jonathan was instructed to visually follow his arm motions to maximize the trunk rotation. Thoracic rotation produces greater intercostal muscle recruitment than straight plane motions (Decramer et al., 1986; Rimmer et al., 1995; Wilson et al., 2001). Jonathan was instructed to continue the exercises at home once he could demonstrate the proper recruitment pattern.

Jonathan's abdominal muscles were often recruited concentrically for exhalation. To retrain the abdominals for quiet breathing, Jonathan was given simple eccentric trunk exercises to be done during his warm-up for soccer. He was told to pair eccentric exhalation (quiet speech) with the eccentric trunk movements to reinforce the natural coupling and avoid the concentric forceful expiratory pattern (Massery, 1994). Jonathan's speech breathing pattern was highly developed, so I incorporated it into his independent neuromuscular retraining program.

A second chest wall stabilizer exercise was added. The patient was positioned supine on top of a vertical thoracic towel roll to maximize thoracic extension and stabilization. Jonathan was then instructed to externally rotate his shoulders while "pinching his shoulder blades" back to the towel roll to maximize anterior chest expansion by recruiting the external intercostals and the pectoralis muscle (using the pectoralis muscles to act as a chest wall expander rather than an upper extremity adductor). The position also stretched his neck flexors. During this activity, he was instructed in take in a deep breath and "hold it" during PNF hold-relax technique to maximize the response from his scapular retractors (Sullivan et al., 1982). This provided maximal positive pressure from within his chest cavity, which provided a greater force to "push out" his chest wall, in order to reduce the pectus forces (Bach & Biandi, 2003; Lissoni, 1998).

Lastly, Jonathan was instructed in specific recruitment of internal intercostals and oblique abdominal muscles as the primary stabilizers of the inferior rib cage to (1) decrease the rib flare deformity, (2) improve midtrunk stabilization to offer the diaphragm better mechanical support, (3) reduce his overdependence on the rectus muscle for stabilization, which again reinforced the development of the pectus, and (4) provide stability of the rib cage during activation of the sternocleidomastoid muscles to prevent the chest from being lifted toward the head when Jonathan's intended movement was to bring his head to the chest. Once again, a PNF D2 upper extremity pattern was used (Knott & Voss, 1968). This time, the patient was positioned supine with his arm positioned in flexion, abduction, and external rotation while lying over a vertical towel roll. The patient's arm was stabilized distally. The patient was asked to "try to lift his arm up in the diagonal pattern" but was not allowed any movement. The result was a strong isometric contraction of the midtrunk muscles (oblique and transverse abdominis and internal intercostals), which are required for stabilization of the trunk before the distal extremity could be moved off the ground. This allowed him to perform small concentric contractions of his internal intercostals and obliques without being overpowered by the rectus. When the patient successfully demonstrated consistency in recruiting these muscles, which was observed by a flattening of the rib flares during the active contractions of the intercostals and obliques, he was instructed to carry over the training independently with higher level postures.

To improve recruitment of thoracic paraspinal muscles, rather than primarily lumbar extensors (to decrease kyphotic forces), Jonathan was instructed in (1) full upper extremity swings in standing during soccer warm-up routine, (2) coordinating slow inhalation with shoulder abduction and scapular adduction, and (3) coordinating eccentric exhalation (counting out loud) when he returned his arms down to his side. He was instructed to focus on recruiting diaphragm and intercostal muscles during inhalation (which should recruit more thoracic extensors) and to concentrate on controlling the eccentric component of the arm and trunk muscles during exhalation.

Neuromuscular Outcomes

Jonathan now demonstrated an effective balance between the primary respiratory muscles (diaphragm, intercostals, and abdominals) during volitional and spontaneous breathing in both quiet breathing and maximal inspiratory maneuvers in multiple postures and activities. Paradoxical movement of the chest wall was no longer noted (improved functional strength of intercostal muscles). No functional thoracic kyphosis was noted during quiet stance or during active recruitment of trunk extensors. Quiet breathing now demonstrated a normal recruitment pattern: (1) initiation of inhalation with the diaphragm and simultaneous chest wall movement, (2) easy inspiratory onset, no apparent effort (low work of breathing, low negative inspiratory force which reduces pectus forces), and (3) smooth continuous movements throughout the inspiratory cycle. Objectively, this was seen with (1) significant increases in mid chest wall excursion measurements (intercostal recruitment) during quiet breathing (tidal volume) in both supine and standing (Table 28-9), (2) a respiratory rate that decreased from 20 to 11 breaths/minute, and (3) phonation support in syllables/breath that increased by 28% (see Table 28-8). Midtrunk stabilization showed marked improvement in strength of oblique abdominal muscles, right still stronger than left. Posturally, this was noted by the elimination of his rib flares and appropriate timing recruitment of the abdominals during trunk stabilization activities both in therapy and as reported by the patient during sports activities. Functionally, the patient reported that he could now run the mile at school without excessive dyspnea or asthmatic symptoms.

Jonathan needed maximal sensory and motor input to change his motor plans for respiration. Verbal cues alone did not produce satisfactory results. Manual, visual, auditory, and positional input in each activity was specifically applied to assist Jonathan in developing new motor plans to improve breathing efficiency and appropriate skeletal forces that promoted normal development of his rib cage and spine.

TABLE 28-9 Chest Wall Excursion (CWE) in Sitting and Supine Positions

TIDAL VOLUME SITTING (QUIET SPONTANEOUS BREATHING)	INITIAL DATE	DISCHARGE DATE 11 MONTHS LATER	REEXAMINATION 4 YEARS AFTER DISCHARGE
Upper chest (level of 3rd rib) upper accessory muscles	1/2″	1/2″	—
Mid chest (level of xiphoid) intercostals	1/4″	3/8″	—
Lower chest (half the distance from xiphoid process to naval) lower intercostals and diaphragm	1/8″	3/8″	—

TIDAL VOLUME SUPINE (QUIET SPONTANEOUS BREATHING)	INITIAL DATE	DISCHARGE DATE 11 MONTHS LATER	REEXAMINATION 4 YEARS AFTER DISCHARGE
Upper chest (Level of 3rd rib) upper accessory muscles	1/8″	1/2″	1/16″
Mid chest (level of xiphoid) intercostals	0″	1/4″	0″
Lower chest (half the distance from xiphoid process to naval) lower intercostals and diaphragm	3/8-1/2″	5/8″	3/4″

Note that, in sitting, improvements were noted in mid and lower chest expansion. No 4-year follow-up measurements.
In supine, all levels increased by discharge, but at the 4-year follow-up examination, the gains in the mid and upper chest had disappeared. Only the lower chest expansion continued to show similar levels to the discharge values.

Integumentary Interventions

No interventions.

FUNCTIONAL OUTCOMES AND QUALITY OF LIFE ISSUES

Following his physical therapy program, Jonathan and his mother noted important functional improvements (Table 28-10). He made the travel soccer team and could play four consecutive games without EIA attacks. His last EIA episode occurred 2 months after starting physical therapy. Prior to physical therapy, he had an EIA episode almost every time he played soccer. At discharge, he could also run the mile in gym class at school without EIA or excessive dyspnea.

He did not miss any days of school for EIA after initiating physical therapy. His mother said that before the physical therapy program, "he would miss 5 to 8 days a year due to sickness related to EIA, but those sick days don't take into account the weekends, holidays, and summer days that Jonathan was incapacitated with asthma-related problems." He had two severe EIA episodes prior to physical therapy that resulted in emergency room (ER) visits. During his physical therapy interval, he did not have any ER visits.

His mother said that in addition to making it possible for him to rejoin his classmates in regular physical activity such as soccer and baseball, following the year of physical therapy, Jonathan began to go swimming again. He had all but given up swimming the year before because of "his deformed chest" and the derogatory comments that were directed at him by other children.

When asked for a general statement about how the physical therapy program affected her son's quality of life, Jonathan's mom said: "It was a miracle. Before we began to see you, Jonathan and I had to focus on his medical condition rather than focusing on being a kid. It completely changed his life." Jonathan and his mother no longer saw him as "disabled" by his pulmonary disease.

DISCUSSION

Jonathan was seen for eight visits over 11 months. The family's motivation to follow through diligently on home programs, and the child's excellent ability to learn new motor strategies, resulted in a minimal number of visits to accomplish the goals of treatment. Under different circumstances, achieving the intervention goals in a similar case may take longer or goals may be less attainable.

TABLE 28-10 Functional Outcomes

FUNCTIONAL OUTCOMES	INITIAL DATE	DISCHARGE DATE 11 MONTHS LATER	REEXAMINATION 4 YEARS AFTER DISCHARGE
EIA attacks or symptoms during sports activities	Frequent	None	None
Length of participation in a sporting activity	5 to 10 minutes before EIA symptoms forced him to stop	Full participation: up to four soccer games per day	Full participation: plays baseball in high school
Complete the "mile test" in gym class	No	Yes	Yes
Average number of days absent from school due to asthma-related complications	5 to 8	0	0
Emergency room visits	2	0	1
Hospitalizations	0	0	0
Daily asthma medications	Yes	No	No

Note that Jonathan's greatest improvements are in activity and health gains.

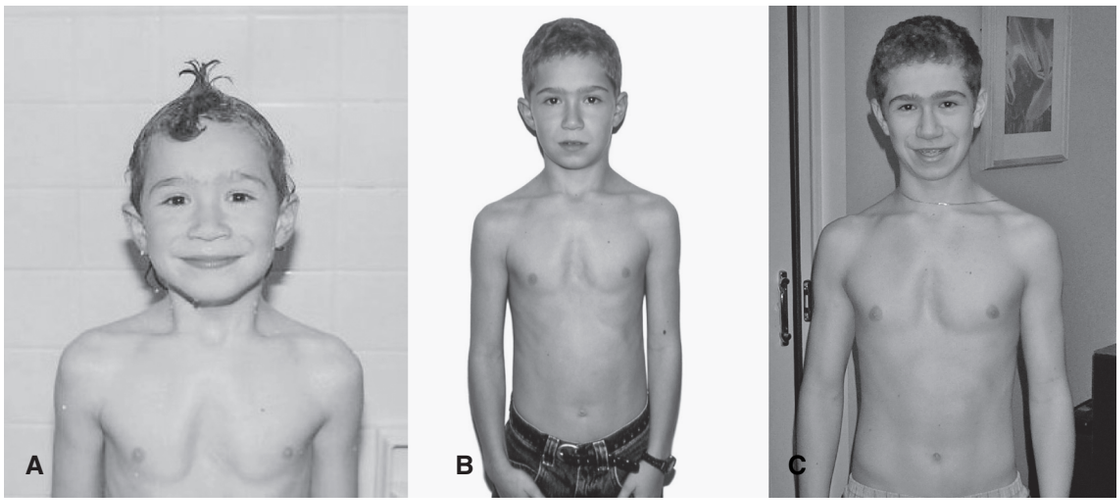
The results of this particular case were marked, but not unrepeatable. Jonathan's physical therapy program was developed from a multisystem and multidiscipline perspective to develop better "external support" for his "internal" asthma. I believe the keys to his success were threefold:

1. A team approach to his condition: recognition by his pulmonologist that his functional limitations were more severe than his medical condition alone indicated, her belief that physical interventions are an integral part of effective management of pulmonary diseases, and her belief that a surgical intervention for his pectus should be the last, not his first, option.
2. A detailed physical therapy examination that focused on identifying the underlying impairments outside of his "asthma and the pectus diagnoses alone," examining both medical and physical impairments to determine which system(s) could account for the severity of his functional limitations.
3. A specific intervention program targeted to reverse or minimize those impairments with a major emphasis on the patient's responsibility in the program (education), and on applying new strategies directly into his daily life (functional).

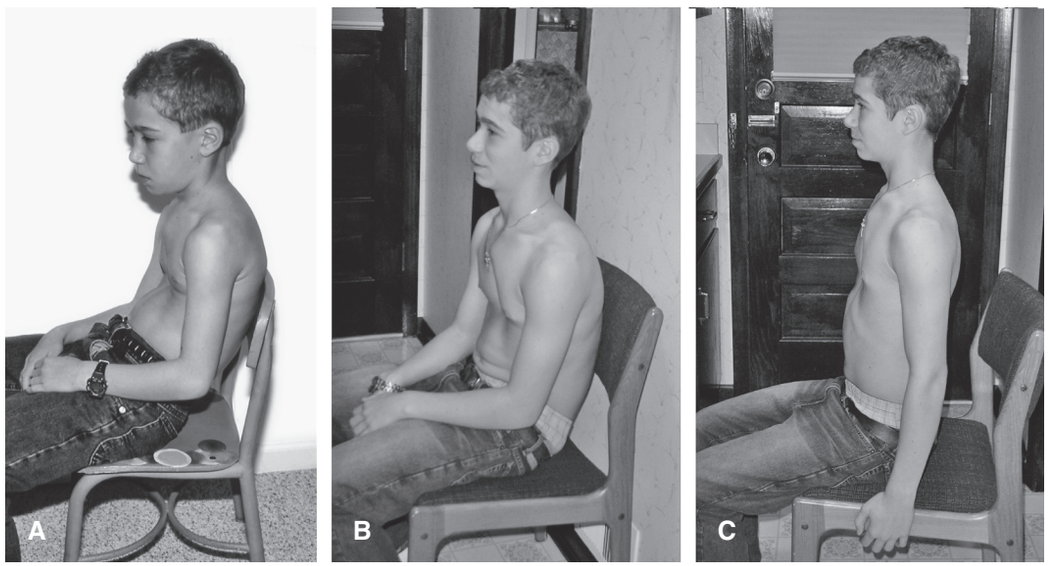
Although it is possible that his changes were due to maturation, it is unlikely according to his mother, who noted that all of his improvements came after the initiation of physical therapy compared to the previous school year without physical therapy.

Jonathan had a complete remission of his pulmonary symptoms following physical therapy, which was not anticipated by this author or his pulmonologist. Physical therapy does not "cure" asthma. Could it be that the EIA diagnosis was not completely accurate? Jonathan had all the symptoms of EIA, but his pulmonary function tests did not confirm the diagnosis. Recently, doctors have begun to explore other possible explanations for EIA symptoms that do not fit the classic picture of asthma, such as vocal fold dysfunction or supraesophageal manifestations of GERD, which present with similar symptoms: high sensitivity to fast inspiratory flow rates, a lack of typical asthmatic responses on pulmonary function tests, and a lack of significant improvement with asthma medications (Wood et al., 1986; Elshami & Tino, 1996; Pierce & Worsnop, 1999; Chandra et al., 2004; Malagelada, 2004; Ay et al., 2004). Because of Jonathan's dramatic improvement with physical interventions, his pulmonologist is now reconsidering his original diagnosis.

The tests and measures used in this case have varied levels of reliability and validity. The medical tests, such as pulmonary function tests and respiratory rates, have long-established reliability and validity (Leiner et al., 1963; Cherniack & Cherniack, 1983). Tests for the physical impairments are not as well established. Tests for phonation length were established in the speech therapy field (Deem & Miller, 2000). Tests for CWE were recently shown to have inter- and intratester reliability, but normative standards for quiet breathing and maximal effort are just beginning to be established (Massery et al., 1997; LaPier et al., 2000). Lateral trunk flexion and the pectus volume measurement have not been validated by research.



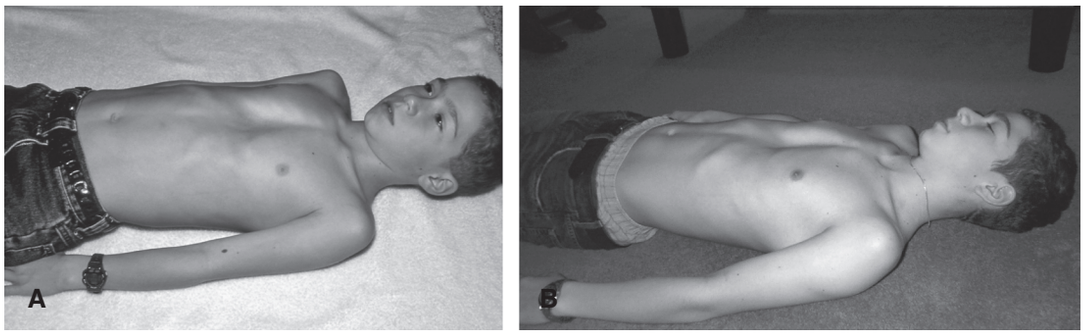
◆ **Figure 28-4** Comparison of pectus excavatum and postural alignments. **A**, Jonathan at 6 years old. **B**, Jonathan at 10 years old. **C**, Jonathan at 14 years old. By 14, Jonathan's pectus has become narrower and more localized. Shoulders are less protracted, resulting in a more neutral resting position. His trapezius is less elevated, and although there is no rib flare noted in either standing posture, adequate abdominal stability is more apparent at age 14.



◆ **Figure 28-5** Comparison of sitting postures. **A**, Typical sitting posture in school per his mother: age 9 and younger. This is a reenactment picture taken at age 10. Jonathan was too embarrassed to have his picture taken of his "deformed chest" when he was initially evaluated at age 9. Note slouched posture (functional kyphosis) with midtrunk fold, pectus, elevated sternal angle. By age 10, patient no longer regularly postured himself like this in sitting. **B,** Jonathan at 14 years old. When asked to slouch in sitting, the midtrunk fold and kyphosis are barely noticeable. Prominent sternal angle is still noticeable. **C**, Straight sitting posture at age 14 years old. Note normal back posture. Mild pectus and mild rib flare still present at base of sternum.

FOUR-YEAR FOLLOW-UP AT AGE 14 YEARS

Jonathan participated in physical therapy for 1 year. Four years after discharge (5 years after initiating physical therapy), Jonathan was contacted, interviewed, and re-examined to assess the long-term effects of this program on his pathology (asthma), his impairments, activity limitations, and participation. Jonathan was 14 years old and a freshman in high school (Figs. 28-4 to 28-6).



◆ **Figure 28-6** Comparison of supine postures. **A,** Discharge picture at age 10. Pectus was reduced almost in half from 34 to 18 mL H_2O displacement measurement during the 11 months of physical therapy. Lower rib flares functionally integrated with abdominal muscles. Neck muscles more elongated. Slight shoulder protraction still noted. **B,** Four years later at age 14. Pectus slightly deeper, but narrower (volume unchanged from discharge at 17 mL). Rib flares more prominent than at discharge. Patient stated that he stopped doing his trunk exercises about 4 months after discharge because he was doing so well. Neck muscles more elongated. Shoulders less protracted.

Medical Update

An examination by his pulmonologist showed no limitations noted in PFT volumes or flow rates. He was also reevaluated by his cardiologist who diagnosed an asymptomatic mitral valve prolapse, which is not uncommon with a pectus excavatum (Fonkalsrud, 2003). No treatment was needed. He had had only one respiratory episode in the last 5 years: a croup-type virus that resulted in a severe bronchitis and his only trip to the ER. He did not have any EIA episode during the 4-year interval. He did not use daily asthma medication. He did, however, report use of his bronchodilator prophylactically when he had a cold "just in case."

Test and Measures

See Tables 28-7 through 28-9 for results of tests.

Functional Outcomes and Quality of Life Update

See Table 28-10 for Jonathan's functional outcomes.

Jonathan received a "perfect attendance award" in eighth grade, which his mother commented was a complete reversal of his school years prior to physical therapy. Endurance is no longer a limitation according to both Jonathan and his mother.

Jonathan's mother reported that he continues to gain confidence both socially and athletically following the physical therapy intervention. She no longer sees any signs of self-consciousness regarding his chest wall deformity. This may be a result of maturation, but she thought it was worth noting because it changed so significantly during and following the intervention period.

Even with 4 to 5 years' reflection since the onset of physical therapy, Jonathan's mother still says that the physical, medical and emotional benefits to her son were incredible. She said that they kept up the home exercises for approximately 4 months after his discharge from physical therapy, but slowly drifted away from them, which may explain some of the minor loss of chest wall mobility upon reevaluation. Jonathan did keep using the strategies that he learned in physical therapy such as maintaining adequate hydration levels and proper warm up before exercise.

Impression

Jonathan has maintained his pulmonary health since discharge 4 years ago with no apparent signs of EIA or its impairments, especially as it affected his endurance and participation in activities and his overall health. At this point, it appears that his asthma or other undiagnosed pulmonary disease is resolved or benign. His spinal alignment is now completely normal, avoiding what appeared to be the likely development of a true thoracic kyphosis. His chest wall deformities are still present but more localized, less noticeable, and do not cause any activity limitations. Recent medical tests also show that his chest wall deformities do not have any measurable impact on his cardiac or pulmonary function. His remarkable gains in individual rib cage mobility from the initial visit to discharge (lateral side bending test) have been nearly retained. Jonathan and his mother stated that they wished they had continued with periodic physical therapy rechecks to maintain all the gains he made during that first year.

I believe Jonathan's physical therapy program worked so well because it was tailored to address his specific EIA pattern and chest wall deformities from a multisystem perspective and included educational, medical, psychologic, and physical perspectives. Interventions by physical therapists can have a tremendous positive impact on the impairments, activity limitations, and resultant disabilities that occur as a result of a primary pulmonary pathology, especially in a maturing system. If the patient cannot breathe efficiently and effectively, then that patient cannot function at his or her highest level. The concepts presented here for Jonathan can certainly be adapted to infants and toddlers as well as older children. The key is to develop a program that keeps the patient, his family, and his resources in mind while developing a targeted intervention strategy.

Following the reevaluation, Jonathan's home program was updated and reinitiated with an emphasis on maintaining his musculoskeletal alignment and trunk control. I recommended quarterly check-ups throughout puberty to modify the program as necessary.

SUMMARY

This chapter presented the pathophysiology and current medical management strategies associated with childhood asthma. In addition, through the use of a single case, ideas for the physical therapy diagnosis and management of physical limitations associated with asthma and its resultant functional limitations were presented through a multisystem and multidiscipline perspective. Impairments in the cardiopulmonary, neuromuscular, musculoskeletal, integumentary, and gastrointestinal systems were assessed for their contribution to the activity and participation limitations that could not be fully explained by asthma alone. An individualized physical therapy program was then presented as a template for other pediatric physical therapy programs. Short-term and long-term results from the physical therapy interventions used with this single case were presented to give the reader an indication of the potential success of such interventions. Obviously, each individual case is unique and must be developed within the context of that particular patient's situation.

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