

Chest Development as a Component of Normal Motor Development: Implications for Pediatric Physical Therapists

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The primary purpose of this paper is to describe normal musculoskeletal development of the thorax within the context of normal motor development of the newborn through 12 months of age. The second purpose is to illuminate the critical need for pediatric physical therapists to identify and treat pulmonary/chest dysfunction. Examples of diagnoses and situations that may lead to adverse trunk/pulmonary development are presented. The final purpose is to present a case illustration of a C5 quadriplegic child followed from 3¼ to 14 years of age with a successful reversal of severe chest wall dysfunction.

The force of gravity interacts with the force generated from muscle contractions to assist in the musculoskeletal development of the infant's thorax.^{1,2} Once the trunk muscles are strong enough, they can work with gravity (gravity assisted) or against it (gravity resisted) throughout all developmental activities. The usual interaction between the musculoskeletal system of the trunk and gravity results in normal development of the thorax. However, weak muscles, which produce a subnormal motor response despite a maximal contraction of the muscle, will not have the same ability to balance gravity's influence, thus altering the important re-

lationship between these two forces.³ Thus, these weak muscles may be detrimental to the development of the chest, indirectly limiting the child's pulmonary function.

A primary neuromuscular impairment, a drug induced state, or a painful condition can all result in chest muscle weakness (Table 1). Resultant labored and/or inefficient breathing patterns secondary to weak musculature and abnormal thoracic development can make it difficult if not impossible for children to achieve higher functional goals.⁴

The purposes of this paper are to (1) describe the normal musculoskeletal development of the thorax as a

Table 1
Possible Causes of Chest Muscle Weakness

Primary	Secondary
Neurological injuries such as spinal cord injuries, spina bifida, myopathies, head injuries, cerebral palsy	Prolonged immobility
Other neuromuscular diseases resulting in developmental delays	Pulmonary or cardiac dysfunction
Congenital diaphragmatic herniation or secondary diaphragmatic dysfunction	Other medical conditions or therapies such as malnutrition, electrolyte imbalances, drug therapies
Direct injury to the trunk muscles	Painful conditions such as orthopedic corrections
	Mechanical misalignment of trunk muscles

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component of normal motor development, (2) illuminate the critical need for pediatric physical therapists to identify and treat pulmonary/chest dysfunction in all their patients in order to optimize function, and (3) present a case illustration in which medical intervention and physical therapy reversed abnormal development in the chest of a spinal cord injured child.



Figure 1. The Newborn. Note triangular shaping and narrow intercostal spacing.

NORMAL CHEST DEVELOPMENT

Breathing is a three dimensional activity, expanding the anterior-posterior, superior-inferior, and transverse or lateral planes of movement of the chest wall. As such, gravity can assist, resist, or have no effect on breathing and movement of the thorax, head, and neck in every posture and activity.¹ When muscle strength and tone are normal, their interaction with gravity and the maturing thoracic skeleton, along with other environmental input, should result in a normally developed adult thorax and neck.⁵

Newborn

The newborn's chest is triangularly shaped in the anterior plane. In a lateral view of the lower chest, it has a circular shape.^{5,6} The cervical area is grossly underdeveloped compared to the rest of the spine making the head appear to rest directly on the thorax. The apex of the upper chest is relatively flat and very narrow. The ribs are horizontally aligned with thin intercostal spacing and little sternal stability. Overall, the thorax occupies about one third of the trunk cavity (Fig. 1).

Internally, the trachea is soft and about one third the diameter of that of the adult. Large conducting airways are present with few alveoli.⁷ Respiratory rate is high, greater than 40 breaths per minute, and tidal volume is low, 18-22 cc.⁸

The infant's physical and motor development at birth gives us a clue to this configuration. The newborn, totally flexed *in utero*, presents at birth with a very tight anterior chest wall. Respiratory accessory muscles, including the

intercostal muscles have not yet developed an optimal length-tension relationship to produce a motor force adequate to significantly move the chest wall or head.⁹ Thus, the newborn is without mechanical resources to expand their chest effectively in all three planes of ventilation, particularly the anterior plane of the upper chest.

As a result, the newborn is a diaphragmatic nose breather with little pulmonary reserve.⁶ As increased activity levels increase pulmonary demands, the newborn responds by increasing his or her respiratory rate. The nonfunctional status of the accessory muscles precludes increasing tidal volume. Paradoxical movement of the upper chest and sternum are not uncommon with increased effort due to the developmental weakness of the chest muscles and the cartilaginous component of the skeletal walls.^{5,10}

Three to Six Months

The baby begins to reach out into his or her environment, thereby developing the agonistic/antagonistic relationship of most upper extremity muscle groups. Maturing extensor tone throughout the trunk is now challenging the predominance of flexion noted at birth.¹¹ The anterior chest wall significantly opens up, especially in the upper chest. The overall configuration of the chest begins to take on a more rectangular shape in the anterior plane. The ribs are still horizontally aligned precluding functional development of the intercostal muscles (Fig. 2).

Underlying pulmonary function shows an increase in tidal volume with a concurrent decrease in respiratory rate.⁸ The child continues to be primarily a diaphragmatic breather, but can now recruit upper anterior chest accessory

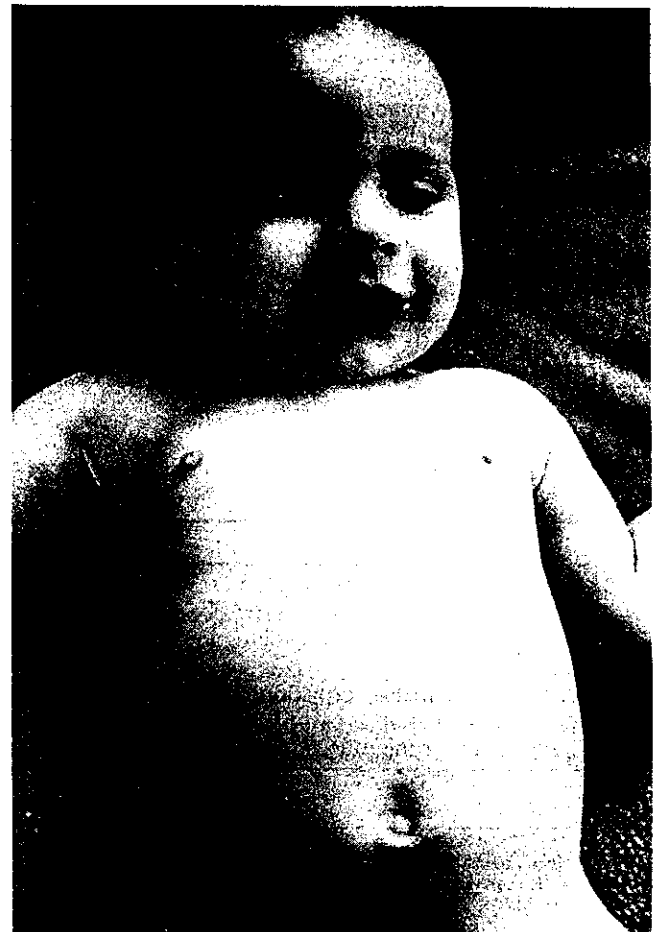


Figure 2. Three to six months old. Note development of rectangular shaping. Ribs still horizontally aligned.



Figure 3. Six to twelve months old. Note good head control and downward rotation of rib cage.

muscles, when they are adequately developed, to assist in ventilation.

Six to Twelve Months

This is the most significant stage in normal early chest development.¹⁰ The child independently assumes upright posture against gravity for the first time, indicating functional muscle strength in all trunk musculature above a fair muscle grade.^{11,12} Ventilation is no longer posturally inhibited by contact with a supporting surface. The child is free to move into and out of gravity's resistance at will, alternating gravity's influence on the chest wall.

At this age, most primitive reflexes are integrated and trunk tone is balanced between flexion and extension components. Head control is well developed, allowing the child to move his or her head independent of trunk movements.¹¹

Most significantly, the upright posture allows gravity and the developing abdominal muscles, to pull and rotate the ribs downward, therefore elongating the chest wall. This rotation is more pronounced in the lower ribs.¹³ As a result, the chest shape becomes elliptical in a lateral view. Proportionally, the thorax now occupies about one half the trunk cavity (Fig. 3).

The downward rotation of the rib cage allows for very significant developments in three important ventilatory muscles groups. They include the diaphragm, the abdominal muscles, and the intercostal muscles.

The diaphragm. The lateral, anterior, and posterior fibers of the diaphragm are attached to the lower borders of the rib cage. As the ribs rotate downward, these fibers follow suit, increasing the domed shape of the muscle, achieving

a more optimal length-tension relationship for diaphragmatic contractions.¹⁴ Abdominal viscera, supported by strong abdominal muscles, provide the necessary intra-abdominal pressure for effective diaphragmatic contractions^{15,16} (Fig. 4).

The abdominal muscles. Functional abdominal strength can now provide (1) the diaphragm with adequate visceral support and (2) the airways with adequate intrathoracic and intra-abdominal pressures necessary for effective secretion clearance.^{15,16} Abdominal contractions also assist gravity in pulling the ribs down into a more elongated state.

The intercostal muscles. Downward rib rotation widens the intercostal spacing, thus achieving an ideal position for intercostal function in both inhalation and exhalation maneuvers. Specifically, the intercostals can now function to: (1) stabilize the chest wall during the negative thoracic pressure created during inhalation, (2) increase the lateral and anterior dimensions of the chest during inhalation, and (3) compress the chest wall during a forceful exhalation.^{15,16}

By 12 months, total lung volume will increase fourfold and the conducting airways, which do not participate in actual gas exchange, will increase threefold.⁸ Utilization of all ventilatory muscles is possible, further augmenting the progression of decreasing respiratory rates and increasing tidal volumes. Pulmonary inspiratory and expiratory reserves can now support changes in lung volumes to accommodate the oxygen demands of increased activity levels rather than relying solely on increasing respiratory rates.⁸

After 12 Months

After 12 months, the musculoskeletal changes become less striking. The ability of the child to disassociate his or her neck from the trunk is fully developed. The shape of the chest is clearly rectangular in the anterior plane. Maturation of the entire trunk musculoskeletal and pulmonary systems occurs during puberty, where another significant period of chest elongation occurs.¹⁷

The slow downward rotation of the rib cage continues throughout the life span.¹³ The aging adult shows a decrease in lung compliance and rib cage mobility, thereby limiting total lung capacity and vital capacity.¹³ This trend in decreased lung volumes may be partially explained by the progressive descent of the diaphragm's resting position

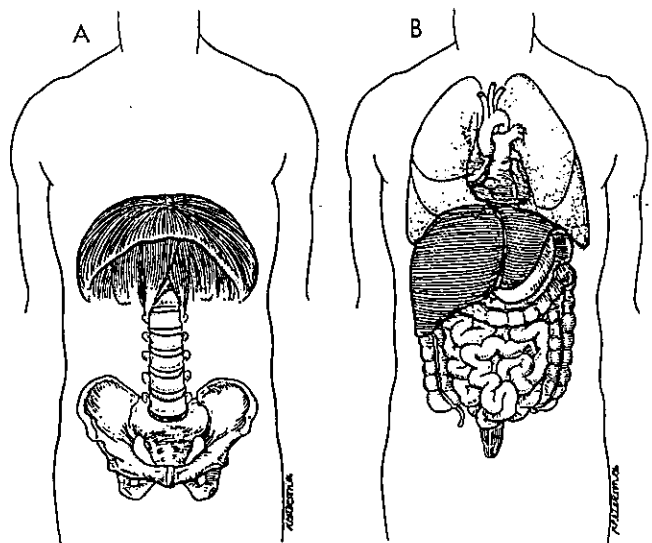


Figure 4. Diaphragmatic positioning. Note high dome shape and its relationship with abdominal viscera. Permission granted for reproduction from Donna Frownfelter, *Chest Physical Therapy and Pulmonary Rehabilitation*, ed. 2., Chicago, Yearbook, 1987.

within the trunk cavity, functionally limiting its ability to increase chest cavity dimensions during inhalation.

ABNORMAL CHEST DEVELOPMENT

Chest development of children with significant functional trunk muscle weakness and/or tonal imbalances does not parallel normal chest development without some external intervention. Because of abnormal muscle/tone function, the disabled child is incapable of independently counteracting or balancing gravity's influence.²

For example, weak abdominal musculature, as seen with a spinal cord injury or with spina bifida, may cause incomplete elongation of the rib cage. The lower borders may "flair up" or "wing" in the anterior plane because they are not pulled down adequately by the abdominals.

Children with a different trunk muscle dysfunction, such as that resulting from a head injury or cerebral palsy, can present a different thoracic abnormality. Those children who demonstrate weak abdominal muscles, but who have the ability to laterally expand the lower chest wall, may develop a lateral flaring of the rib cage. If they are positioned much of the time in supine, the lower borders of their rib cage are likely to flair out laterally because this motion is in a gravity eliminated plane.¹ Thus either anterior or lateral flaring of the rib cage may be seen in children with varying neuromuscular weakness.

In either example, lack of adequate abdominal strength lowers the viscera's position, causing the diaphragm to maintain a lower resting place in the abdominal cavity. This reduces the diaphragm's effectiveness, subsequently decreasing potential chest expansion and lung volume capabilities.¹⁸ Possible causes of trunk muscle dysfunction are listed in Table 1.

In almost all cases, adverse changes are most dramatic in the upright posture.¹⁸ The child, who lacks posterior support from the paraspinal muscles, from a paraplegic or quadriplegic condition, will collapse into a flexed, kyphotic posture further compromising pulmonary function (Fig. 5). Chest expansion will be severely compromised in the anterior and inferior planes. Obviously, children with these deficits will have great difficulty attending to other functional upright tasks unless their pulmonary status is corrected or compensated for.

If a child lacks adequate intercostal muscle support, the chest wall may be drawn in towards the lungs due to the negative pressure gradient generated during inhalation. The



Figure 5. Age 3 $\frac{3}{4}$. Note severe chest deformities prior to physical therapy intervention. Permission granted for reproduction from Donna Frownfelter, *Chest Physical Therapy and Pulmonary Rehabilitation*, ed. 2., Chicago, Yearbook, 1987.



Figure 6. Age 6. Note upright posture alignment in body jacket. Underneath, chest wall deformities are reducing: rib rotation begun, upper chest development significantly improved, and reduction noted in lower chest wall flaring. Permission granted for reproduction from Donna Frownfelter, *Chest Physical Therapy and Pulmonary Rehabilitation*, ed. 2., Chicago, Yearbook, 1987.

anterior-posterior and transverse dimensions of the chest thus decrease rather than increase during inhalation. Visually this may be seen as intercostal retractions or in more severe cases as a pectus excavatum deformity¹⁹ (Fig. 5).

In summary, intercostal, abdominal, or spinal extensor muscle weakness can cause secondary problems that impede the effectiveness of an intact diaphragm. Thus, this weakness directly limits expansion of the chest wall in any/all three planes of ventilation. Internally, the result is decreased pulmonary function.

EARLY PHYSICAL THERAPY

Infants with disability should be positioned with optimal chest development in mind, whether residing in the Intensive Care Unit or a home setting. For example, feeding positions that reduce pulmonary stress should be elected. Attempts should be made to avoid prolonged singular positioning. The child should be placed in a variety of positions throughout the day. Comfortable breathing patterns should be considered when choosing sleeping positions. Overall, the infant's ease of breathing, rather than the caregivers' ease of service, ought to be the primary criteria for the infant's positioning.²⁰

When the child is ready to begin upright activities, he or she must have adequate trunk support to promote optimal pulmonary function and chest development. Simple handling techniques such as the "prone" upright position (child's chest supported by contact with the caregiver's chest) may be used. Additional use of a folded receiving blanket placed against the infant's mid-chest region may provide increased chest stability while allowing freer inferior and anterior diaphragmatic excursions in this posture.

Older children may need handling techniques to stabilize their pelvis while working toward independent sitting activities. For example, manual stabilization of the child in an anterior pelvic tilt can facilitate active upper trunk extension. Concurrently, this procedure will also free up the anterior chest wall for greater chest expansion maneuvers.

For children requiring a great deal of support in upright, a variety of equipment is available. Visceral placement may be achieved with an abdominal binder, substituting the normal support of the abdominal wall with an elastic support.²¹ Those children needing more support may have success with a body jacket (full contact thoracic lumbar

sacral orthosis). Care must be taken to check the orthosis for proper fit and abdominal cut out. Without such, the anterior chest wall excursion will be restricted, thus compromising pulmonary function (Fig. 6). Other equipment concerns include wheelchair positioning, seating devices, lateral trunk supports, and standing devices.

Positioning is only one aspect of an effective pulmonary/chest development program for children with a movement dysfunction. Traditional treatment modes such as postural drainage and coughing and breathing exercises are also important components.²²

CASE ILLUSTRATION

The following case study illustrates the long-term benefits of incorporating a comprehensive pulmonary program into an overall treatment plan.

M. F. was born full term with a traumatic C5 spinal cord injury as a result of a complicated breach vaginal delivery. At 7 months old, following a prolonged cold, a tracheostomy was performed for ease of airway clearance procedures. The child never received physical therapy prior to 3¼ years of age because her pulmonary physician indicated to the family that she was too ill (Fig. 5).

At that time M.F. showed severe chest and ventilatory abnormalities, including a severe pectus excavatum, intercostal retractions, pronounced anterior flaring of the lower borders of the rib cage; triangular shaping of the chest, underdevelopment of the upper accessory muscles, high respiratory rate, low tidal volume, paradoxical breathing, inability to spontaneously alter this breathing pattern, and the need to be suctioned at least 24 times per day. M.F. was intolerant of upright positioning, complained of severe dyspnea, demonstrated the inability to phonate (only 1-2 syllables/breath), and displayed a forward head and jaw posture in upright.

Physical therapy included: (1) increased positional changes and initiation of self movement activities, such as rolling and rocking in her own rocking chair; (2) a comprehensive pulmonary program, including prophylactic chest physical therapy and the use of multiple effective assistive cough techniques; (3) therapeutic exercise techniques aimed at altering her breathing pattern to include the use of upper chest ventilatory muscles; (4) general strengthening, range of motion, and activities of daily living training that focused on incorporating M.F.'s respiratory goals with her mobility goals; (5) breath support training to improve phonation skills; and (6) procurement of proper equipment, such as a well fitted wheelchair and body jacket to optimize upright posture and pulmonary function.

Within 2 months of treatment M.F. showed significant progress, especially in breath support areas. She was able to phonate eight syllables/breath with significantly louder phonations, and she began using full sentences rather than phrases. The paradoxical movements of her chest during inspiration had ceased, her respiratory rate decreased, and she could hold her breath for 10 seconds. M.F. successfully learned to balance her strong diaphragm with her upper accessory muscles. Suctioning was only necessary about 12 times/day. Developmentally, she was able to roll from supine to prone with minimal assistance, and she inconsistently rolled independently from prone to supine. She independently rocked in a rocking chair (with her body jacket on) for up to 1 hour.

By 6 years of age, she had begun night time mechanical ventilation due to cor pulmonale and general failure to thrive. Chest wall deformities hidden under the body jacket seen in Figure 6 were dramatically reduced. Her ribs now rotated downward, the lower chest wall flaring was minimized, and marked development of the upper chest occurred. Her phonation skills continued to progress, upright



Figure 7. Age 12. Dramatic improvement in chest wall structure. Note absence of pectus excavatum.

posture was tolerated all day without complaints of dyspnea, and lung volumes improved. Neutral head and neck positioning in upright was normal due to the optimal thoracolumbosacral positioning obtained with her body jacket and wheelchair (Fig. 6).

At 12 years of age, a spinal fusion with Harrington rod placement was performed for upright support, replacing the need for the body jacket (Fig. 7). An abdominal binder continues to be necessary to provide visceral support. Chest wall deformities were all reversed. M.F. continued with mechanical ventilation about 22 hours/day.

Presently, M.F. is 15 years old and a mainstream honor roll high school student. She lives at home where her family and a nurse support her physical and pulmonary needs, including the nearly continuous use of positive pressure ventilation. M.F. has not been hospitalized for a pulmonary complication in 4 years. Her pulmonary function tests values indicate voluntary lung volumes adequate to support independent breathing, but she and her family are uncomfortable with the idea of weaning at this time. These overall successful physical and pulmonary gains were brought about through an aggressive, coordinated medical and therapeutic program.

CONCLUSION

Regardless of diagnosis, all children must be able to comfortably breathe before effectively attempting any other physical activity. Immobility and weakness of the trunk from any pathology will adversely effect the development of the musculoskeletal system of the thorax, indirectly impairing pulmonary function. Understanding this, the pediatric phys-