Mary Massery's

LINKED: BREATHING & POSTURAL CONTROL

Instructor

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Sponsored by

Nebraska Physical Therapy Association

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7.5 Contact Hours

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COURSE DESCRIPTION

This course will challenge the practitioner to make a paradigm shift: connecting breathing mechanics and postural control with management of trunk pressures. Through Dr. Massery's model of postural control (Soda Pop Can Model), the speaker will link breathing mechanics with motor and physiologic behaviors (a multi-system perspective). She will present novel research demonstrating the role of vocal folds as postural stabilizers, extending the concept of "core stability" from the vocal folds on the top of the trunk to the pelvic floor on the bottom. Numerous interventions will be presented that use positioning and ventilatory strategies to optimize motor performance. The emphasis of the course will be on developing practical, quick clinical solutions for pediatric and adult patients in all practice settings.

COURSE OBJECTIVES

At the conclusion of the course, participants should be able to:

1. Describe how trunk pressures link breathing and postural control using the Soda Pop Can Model.
2. Describe the multiple, simultaneous roles of the diaphragm as related to breathing, postural control, gastroesophageal reflux, constipation, and venous return.
3. Demonstrate the role of the vocal folds in normal postural stability responses (balance) and make the case for using speaking valves for patients with tracheostomies.
4. Contrast normal infant chest wall development to those with impaired breathing mechanics.
5. Position patients for optimal physiological and biomechanical support of breathing with simple equipment (towels, pillows, etc.).
6. Use a ventilatory strategy algorithm presented in class to optimally match breathing with movements from bed mobility to athletic endeavors.

MASSERY PHYSICAL THERAPY

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SPEAKER'S BIOGRAPHY

Nechama Karman, PT, MS, PCS

Nechama Karman received her MSPT from Columbia University in 1994, her Advanced MS in orthopedic PT from Touro College in 1998, and has completed her Health Sciences PhD coursework at Seton Hall University. She has held academic appointments at both Hunter College and NYIT, and is also an APTA board-certified pediatric clinical specialist.

Nechama is chief clinical educator at Mobility Research, providing pediatric and adult trainings, introductory and advanced seminars, webinars, and clinical support for LiteGait in the USA and internationally. She is a primary instructor in LiteGait's "train the trainer" program. She also owns a private practice in New York City focusing on treating patients with complex neurological conditions and/or complex pelvic conditions.

Nechama has been a teaching assistant for Mary's courses for over a decade and completed a 2-year faculty apprenticeship in 2016, becoming Mary's first certified faculty member! One of Nechama's proudest "Mary Massery" moments occurred when she treated a man suffering from prostatectomy-related incontinence using Mary's approach. She taught him to transfer without incontinence for the first time in 9 months - all in under 15 minutes! She is passionate about helping other therapists learn these important concepts.

BREATHING AND POSTURE: A MULTI-SYSTEM EVENT!

Part I: Pressure Control

I. Pressure! Successful coordination of postural stability and respiratory mechanics depends on how well the patient with motor impairments:

A. Generates trunk pressure
B. Regulates trunk pressure
C. Maintains trunk pressure
D. And successfully manages those pressures in both the thoracic and abdominal cavities

1. *Intra-thoracic pressure (ITP)*
2. *Intra-abdominal pressure (IAP)*
3. *Clinical examples of poor pressure regulation in pediatric and adult cases in upright and recumbency*

a) Matthew, 1 ½ y/o, with cerebral palsy following extreme prematurity
b) Larry (normal) and Steve (C5 SCI), both 26 y/o. Steve's chest was normal before SCI 9 months ago. Now "crushed" by gravity. Inadequate proximal pressures.
c) Gracie, 7 months old and able to produce appropriate ground reaction forces to maintain upright, demonstrating adequate proximal pressures.
d) Melissa, 3 ½ y/o C5 SCI, birth complication


Larry: normal


Steve: C5 SCI

E. Problem established! How does it relate to breathing mechanics?

II. "Soda-pop Can" Model of Postural Support (Massery 2005, 2006, 2013)

A. Clinical Example: Melissa, C5 SCI due to birth trauma

1. *Acquired musculoskeletal deformities due to "crushing" force of gravity*
2. *Inability to counteract gravity: inadequate reaction forces or poor proximal pressure*


Melissa C5 SCI

B. What makes a thin aluminum soda-pop can "strong"?

1. *Closed system*
2. *Positive pressure from the carbonated gases inside the can is greater than the atmospheric pressure exerted upon the can, creating functional strength for the weak external can much like our own skeletal structure.*
3. *The exterior aluminum can is weak: easily crushed if the top is open.*

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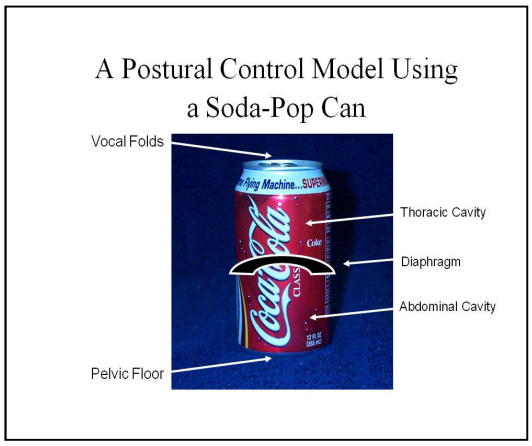
C. Components of our own "aluminum can" (trunk)

1. *Diaphragm:*

    a) Completely divides the upper and lower trunk into 2 chambers: thoracic and abdominal.
    b) Diaphragm is the body's **major pressure regulator**.
    c) Respiration needs pressure regulated in both cavities in order for the lungs to function.
    d) Diaphragm plays a significant role in:

        (1) *Enhancing respiration*
        (2) *enhancing postural control*
        (3) *stimulating lower gastrointestinal motility*
        (4) *suppressing gastric reflux forces*
        (5) *enhancing venous return*



2. *Two internal pressure cavities*

    a) thoracic cavity - Intra-thoracic pressure (ITP)
    b) abdominal cavity – Intra-abdominal pressure (IAP)

3. *Top of cylinder: vocal folds and other glottal structures*
4. *Bottom of cylinder: pelvic floor*
5. *Three horizontal valves contain the thoracic and abdominal pressures*

    a) two external valves: vocal folds (top) and pelvic floor (bottom)
    b) one internal valve: diaphragm (middle)

D. Normal pressures: intra-abdominal pressure (IAP) and intra-thoracic pressures (ITP)

1. *Internal trunk pressures determined by interaction of trunk muscles (from vocal folds on top to pelvic floor muscles on bottom) and horizontal valves*
2. *Normal adult intra-abdominal pressure (IAP):*

    a) Abdominal cavity is the high pressure system compared to thoracic cavity and atmosphere, so IAP is always positive
    b) IAP increases during inhalation and decreases during the exhalation.
    c) Supine at rest

        (1) *Healthy weight adults: IAP 5 – 7 cm H_2O*
        (2) *Obese adults: IAP 9 – 14 cm H_2O*
        (3) *Higher BMIs correlated to higher resting IAP*

    d) IAP triples in upright (sitting & standing): 16-20 cm H_2O (higher in standing)

3. *IAP increases with:*

    a) Higher postural demand activities or higher respiratory demand (increased work of breathing).
    b) Individual movement strategies (dynamic postural control) will lead to huge variability among subjects.

c) Examples of IAP during common motor tasks:

(1) *Sitting to standing: 37 cm H_2O*
(2) *Lifting 10 lb. weight: 12 cm H_2O*
(3) *Lifting 20 lb. weight: 20 cm H_2O*
(4) *Squatting: 25 cm H_2O*
(5) *Cough: 80 - 160cm H2O or higher*
(6) *Jumping: 171 cm H_2O*

4. *Normal intra-thoracic pressure (ITP)*

a) Lower pressure system relative to atmosphere (negative pressure) during inhalation which pulls the atmosphere (air) into the lungs.
b) Higher pressure relative to atmosphere (positive pressure) during exhalation.
c) ITP can be dramatically increased if the exit (glottis) is restricted such as with a coughing or yelling, or closed, such as with breath holding.
d) Small ITP changes drive airflow direction:

(1) *Inhalation moment created when ITP decreases at least 3 cm H2O*
(2) *Exhalation moment created when ITP increases at least 3 cm H2O*

5. <u>*Practical Session*</u>*: Shoulder flexion and breath response in standing*

a) Feet together, elbows straight, raise both arms up into full shoulder flexion. Did you spontaneously inhale, exhale or no change? (You should notice spontaneous inhalation.)
b) Repeat with bent "lazy" elbows. You should experience no spontaneous drive to inhale or exhale because ITP was not changed. The upper extremities were not functionally linked to the trunk (bent elbows), thus the rib cage was not "required" to expand to complete the motor task. Therefore, ITP did not become negative, so there was no spontaneous inspiratory drive.


Normal Restricted

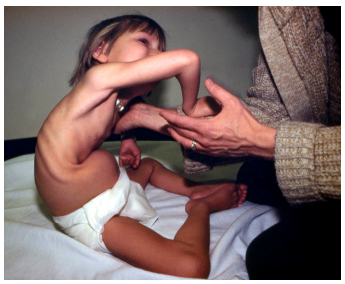
6. <u>*Significant Research in this area*</u>*: Hodges 2000, Cobb 2005, Lambert 2005, Chionh 2006, Addington 2008, DeKeulenaer 2009, Yamasato 2014, Shaw 2014*

E. Primary muscles involved in <u>generating, maintaining and regulating pressure</u> in the abdominal and thoracic chambers

1. *intrinsic laryngeal muscles*
2. *intercostals*
3. *diaphragm*
4. *abdominals*
5. *paraspinals*
6. *pelvic floor muscles*

F. Examples of positive pressure compromised: A breach in pressure regulation will result in the loss of the trunk muscles' ability to generate, maintain and regulate pressure in both chambers, causing collapsing forces on the skeleton and internal organs. Examples:

1. *<u>tracheostomies</u>: bypasses vocal folds, thus inability to create sustained positive ITP.*
2. *<u>intercostal weakness/paralysis:</u> collapse of the anterior chest potentially causing a consequential pectus excavatum.*
3. *<u>diaphragm weakness/paralysis</u>: major deficiency in both breathing mechanics and postural stabilization (balance).*
4. *<u>abdominal weakness/paralysis</u>: allows excessive anterior excursion of abdominal viscera potentially resulting in inadequate positive IAP needed for control of the lumbar spine, optimal breathing mechanics, normal GI motility, etc.*


Melissa C5 SCI

5. *<u>paraspinal weakness/paralysis:</u> total kyphotic posture (long "C" shaped curve) limits anterior trunk expansion, limiting development of normal IAP and ITP. May compromise breathing, postural control, and other internal organ function.*
6. *<u>pelvic floor dysfunction</u>: inadequate ability of muscles to support the positive pressure exerted on the pelvic floor may result in incontinence or prolapse.*
7. *<u>other structural changes or motor control changes:</u> may compromise the ability of the whole 'soda-pop can' to generate appropriate pressure support for the limb force production through the extremities, and may result in:*

    a) elbows bending while weight bearing in spite of 'normal' tricep muscle strength
    b) hips and knees bending while weight bearing in spite of 'normal' gluteal and quadricep muscle strength

G. <u>Practical Session</u> – Vocal folds as a postural stabilizer

1. *Demonstrating the role of the glottis in dynamic postural control*
2. *Pushing your partner in standing without the engagement of the glottis ("Ha" sigh) causes balance impairment*

III. Take Home Messages

A. Breathing, postural control, and the trunk pressures needed for optimal motor function, <u>cannot</u> be assessed or treated separately!

B. All the trunk muscles <u>work together</u> to support postural stability <u>as well as</u> to provide <u>simultaneous</u> support for their primary functions such as respiration, limb force production, balance and continence.

V. Body systems influencing postural control

A. Obvious systems

1. *Musculoskeletal (MS)*
2. *Neuromuscular (NM)*

B. Less obvious systems

1. *Cardiovascular/ Pulmonary (CP)*
2. *Integumentary (skin and other connective tissue) (INT)*
3. *Internal Organs (IO)*

    a) especially Gastrointestinal (GI)

VI. Clinical problem: Congenital pectus excavatum (sunken chest)


Ryan 16 y/o
pectus excavatum

A. Ryan 16 y/o, congenital pectus excavatum

B. Secondary postural impairments

1. *Increased risk of developing pain conditions due to joint mal-alignment and repetitive stress on musculoskeletal system*
2. *Common areas that develop pain and/or decreased range of motion: head/neck, shoulders, and/or low back*

VII. Skeletal Support for posture and respiration (***Netter 2003, Plate 178***)

A. Skeleton of the thorax - Anterior support

1. *Ribs - 12 individual ribs*

    a) Designed for <u>mobility</u> at the expense of <u>stability</u>
    b) Primary roles

        (1) *stabilize ribs during negative pressure of inhalation*
        (2) *provide lateral expansion of the ribs*
        (3) *unilateral activation of internal and external intercostals provides axial rotation of the trunk (spine)*

    c) Each rib: single articulation with costal cartilage, which in turn articulate with the sternum body with a single articulation
    d) <u>True Ribs</u>: Ribs 1-7

        (1) *inserts to sternum via their own cartilage*
        (2) *more stable than false ribs*
        (3) *in some pediatric cases, the true ribs may not adequately elongate downward thereby preventing the intercostal spacing from widening. May result in a visual appearance of a small upper chest and in some cases, it may appear as a separation between the true and false ribs.*

f) False Ribs: Ribs 8-12

(1) *more mobile than true ribs due to increased length of the lever arm and longer cartilaginous segment*
(2) *ribs 8-10 insert to sternum through 7th rib cartilage.*
(3) *In addition to their role in respiration, expansion of false ribs laterally is used for balance and reaching tasks in a coronal plane.*
(4) *ribs 11-12 are struts and do not insert to the sternum. Primary role is to aid trunk stabilizers.*

g) Boney landmarks of anterior rib cage

(1) *ribs 1 – 3: between clavicle and axilla*
(2) *ribs 4 – 7: "sports bra" area*
(3) *ribs 8 – 10: inferior to the "lower bra strap" or "bathing-suit top" line*
(4) *"Bow tie" (Mary's term): lower sternum and false ribs. Represents the most mobile segments of the anterior chest, thus least capable of withstanding deforming forces.*

2. *Sternum - mobility driven*

a) Three component parts

(1) *Manubrium (top). Superior landmark: Suprasternal notch (jugular notch)*
(2) *Body (middle). Longest segment.*
(3) *Xiphoid process (bottom). Inferior sternal landmark. Most mobile segment.*

b) Sternal angle: junction between manubrium and sternal body

(1) *level of the second rib*
(2) *level of the carina: bifurcation of trachea into mainstem bronchi*
(3) *reliable boney landmark for palpating individual rib segments*
(4) *landmark used for manual techniques to control movement of the entire anterior chest*
(5) *Palpating sternal angle:*

(a) place one index finger at the suprasternal notch, say your right hand.
(b) place your left hand sideways across the manubrium (parallel to the ground) snuggly meeting your left index finger to your right index finger.
(c) move right index finger down to just under your left baby finger.
(d) Your right index finger should be on or just below the sternal angle.
(e) the length as the manubrium is approximately the same length as the width of 3 to 4 fingers.
(f) Use the patient's own hand to be accurate.

4. *<u>Functional movements</u> - three potential planes of movement*

a) Potential mobility of the chest

(1) *potential mobility increases as you move inferior on rib cage*
(2) *potential mobility increases as you move anterior on rib cage*
(3) *therefore, the most potential mobility lies along the xiphoid process and the inferior borders of the anterior and lateral ribs (bow tie)*
(4) *rib cage deformities are commonly noted here such as pectus excavatum, inspiratory rib retractions, or rib flares of lower ribs*
(a) medial rib flares usually associated with weak/dysfunctional rectus muscle.
(b) lateral rib flares usually associated with weak/dysfunctional external oblique muscles.

b) Rib cage: Primary planes of movement

(1) *upper ribs - move primarily anterior and superior*
(2) *middle ribs - transition between the upper and lower ribs, all 3 planes of movement fairly equal*
(3) *lower ribs - move primarily lateral and superior*

c) Movements for 'normal' inspiration

(1) ***THERE IS NO NORMAL BREATHING PATTERN!!!***
(2) *Because the rib cage is very mobile, its movements are easily influenced by genetics as well as external factors such as posture, sex, height, weight, activities, and even self-esteem.*
(3) *Rib cage movements during inspiration depend on the alignment of the rib cage with the rest of the trunk (pelvis and spine), superimposed on the inspiratory motor strategies of the individual.*

B. Skeleton of thorax - posterior support (*Netter 2003, Plate 178*)

1. *Thoracic spine / posterior thoracic cage*

a) Vertebral column is "stacked" providing mechanical support for upright postures
b) Thoracic spine provides stability to the rib cage and vice versa.

2. *Posterior rib landmarks*

a) Boney landmarks of the posterior rib cage

(1) *Rib 2: ~ superior border of scapula*
(2) *Rib 4: ~ spine of the scapula*
(3) *Rib 8: ~ inferior border of scapula*
(4) *Rib 12: lowest most palpable rib (floating rib)*

b) Surface Anatomy posterior trunk (*Netter 2003, Plate 145; Kendall 1993, p11*)

(1) *C7: prominent spinous process*
(2) *T7-8: inferior border of scapula*
(3) *T12:*
(a) lowest palpable rib
(b) insertion of lower trapezius
(c) lays inferior to scapula and superior to waist

(4) *L4: level with iliac crest*

3. *Thoracic vertebrae and rib articulation (Netter 2003, Plate 147& 179)*

a) Head: two articulating surfaces for superior and posterior costotransverse ligament attachments to vertebral body
b) Neck: no articulations with ribs
c) Tubercle: articulation with transverse costotransverse ligament to transverse process
d) Body: main shaft of rib
e) Posterior rib angle: posterior rib angle (under scapulae)

(1) *Most posterior segment of rib*
(2) *Natural resting position is under medial border of the scapulae for ribs 2-8*

4. *Rib / vertebral articulations: very stable (Netter 2003, Plate 147 & 179-180)*

a) Posterior junctions

(1) *lateral costotransverse ligament (axial rotation of thoracic spine)*
(2) *superior costotransverse ligament (extension/flexion)*
(3) *inferior (or posterior) costotransverse ligament (extension/flexion)*
(4) *inter-transverse ligament (small, vertical ligament connecting transverse processes of adjacent vertebrae, lateral side bending)*

b) Anterior junctions

(1) *radiate ligament of the head of the rib (attaching rib to same number thoracic vertebrae and one vertebrae higher)*
(2) *anterior longitudinal ligament along entire spine*

C. Clinical Examples

1. *When thoracic spine is flexed or kyphotic, the posterior rib angle is pushed more posterior, in turn, pushing the scapulae into a protracted position*

a) Ryan – pectus excavatum and secondary postural impairments

2. *Dynamic consequences: Positioning:*

a) Grady - premature, multiple medical complications:
b) flexed spine – lateral scapulae – forward head – open mouth – poor swallow – possible dysphagia/drooling – aspiration – pneumonia

Grady 5 y/o, prematurity, chronic lung disease

BREATHING AND POSTURE: A MULTI-SYSTEM EVENT!

Part II: The Diaphragm

I. Research support: Dual nature of postural control and breathing

(Additional references in bibliography. Key research is highlighted in this handout. Lecture slides will introduce new literature as it becomes available.)

A. The diaphragm is both a respiratory muscle and a postural muscle.

1. *Seminal work: Trunk muscles are both respiratory and postural muscles*
    a) Hodges & Gandevia 2000
    b) Needle EMG of diaphragm and abdominal muscles demonstrating that respiration and postural control were indeed linked!
    c) Diaphragm and abdominal muscles increase postural response with increased postural demand, while continuing to synchronize movement for respiration as well.

B. Reconfirmed by many researchers over the next several decades.

1. *Kolar 2010: like Hodges' earlier work, Kolar demonstrated diaphragm's simultaneous role as a postural stabilizer in healthy subjects using fMRI - isometric UE & LE tasks in supine resulted in increased diaphragm recruitment compared to breathing alone.*
2. *Kolar 2012: applied same tests to pain population: chronic LBP subjects showed decreased diaphragm recruitment and excursion in response to increased postural demand (UE & LE isometric task) compared to healthy controls. This may contribute to etiology of LBP.*
3. *Hamaoui 2014*
    a) *Bilateral electric stimulation of the phrenic nerves resulted in a balance disturbance, but the response was in opposite directions in sitting and standing postures. Sitting: center of mass moved anterior. Standing: center of mass moved posterior.*
    b) *Unilateral stimulation of a phrenic nerve resulted in an additional plane of motion disturbance to balance. Again, the reaction was in opposite directions in sitting and standing. Sitting: center of mass moved laterally to the non-stimulated side, as well as anterior. Standing: it moved laterally to the stimulated side as well as posterior.*
    c) *My summary – diaphragm plays an active role in normal balance response in upright. Unique clinical application: unilateral diaphragm weakness/paralysis may cause a greater disturbance to balance than a symmetrical diaphragm impairment.*
4. *Smith (2006 - 2016)*
    a) *Numerous studies >10,000 Australian women across adulthood*
    b) *Multi-tasking trunk functions: Links difficult breathing, incontinence, GI dysfunction, LBP, and balance impairments*
    c) *When one symptom is present, there is an increase risk on developing another adverse symptom.*
    d) *My summary - Breathing cannot be separated from other trunk function! They are all interactive and interdependent.*
5. *Similar findings: diaphragm & balance are linked.*
    a) *Gandevia 2002, Caron 2004, Vostatek 2013,*

C. Physiologic as well as a physical response to the demand for postural control: The cardiopulmonary system's unique role in movement

a) *Hodges 2001: When faced with conflict between physiology (breathing) and physical support, the diaphragm will ALWAYS choose breathing over postural control*
b) ***My take-away: Breathing Always Wins!***

D. Research has since confirmed these initial studies and has gone on to show many more connections between the physiology of breathing and postural control

1. *Janssens*

a) 2010 - *Respiratory muscle fatigue was linked with ineffective postural control strategies for controls (distal rather than proximal control) which was similar to LBP patients and may contribute to high recurrence of LBP.*
b) 2013 - *pattients with COPD showed similar postural control deficits as LBP. COPD patients with greater inspiratory muscle weakness, showed the greatest balance deficits (distal (ankle) postural control strategies rather than proximal (back muscles)).*
c) 2015 – *treatment of 8 weeks IMT (inspiratory muscle training) with LBP: resulted in improved proximal control strategies (increased recruitment of back muscles rather than ankle muscles (proximal rather than distal)) for balance, and decreased report of LBP.*
d) *Mary's Summary: Diaphragm weakness appears to result in the diaphragm's increased focus on breathing and decreased focus on its postural control role (seen as balance deficits).*

2. *More studies link trunk control, breathing and physiology. Physiology always wins!*

a) *Smith 2016 – Severity of COPD is positively associated with greater balance deficits likely due to increased focus of the trunk muscles on breathing rather than postural control.*

3. *Adult obesity:*

a) Morbid obesity causes adverse increase in IAP (intra-abdominal pressure) which has been identified as the likely cause of systemic hypertension (Varela 2009).
b) Pressure related co-morbidities such as gastroesophageal reflux disease, hernias, stress incontinence, diabetes, hypertension, and venous insufficiency showed increased prevalence, especially for obese patients with IAPs of 12 cm H_2O compared to obese patients with IAPs 9 cm H_2O (Lambert 2005).
c) Kuczynski 2008, Lamberg 2012, David 2015, Gamboa 2015, others

E. Abundant research confirmed: the trunk muscles are simultaneously respiratory & postural muscles!

F. Emerging Research:

1. *"Top of the Can" - vocal folds as postural stabilizers (to be discussed later in this lecture)*
   a) *Hagins 2004 & 2006, Orlikoff 2008, Massery 2013*

II. Research – GI and pelvic floor

A. GERD has far reaching motor and health implications for asthma, Sandifer's syndrome, sleep dysfunction, and others:

1. *Wirth 2016: Sandifer Syndrome. Dystonic movements of 5-month old infant resolved when GERD was appropriately treated.*
2. *London (Kobernick) 2009: 2-year prospective study, 62 school kids, moderate non-atopic (non-allergic) asthma. 2/3 had GERD. 32/44 were treated for GERD (meds &/or surgery) as well as asthma: 75% decrease in asthma exacerbations (0.7 incidents/yr) compared to non-GERD group (2.9 incidents/yr). Doctors may be under-estimating the benefit of identifying and treating GERD in kids with non-atopic asthma.*
3. *Other: Borowitz 2004, Bhatia 2009, Peterson 2009, Tolia 2009*

B. Pelvic floor dysfunction

1. *Button et al 2006: Prevent, Control & Treat Urinary Incontinence in Cystic Fibrosis & COPD (European CF Conference)*

   a) 37 CF women (19-61 y/o) 67% incontinent
   b) 22 COPD women (48-77 y/o) 59% incontinence
   c) 66 normal controls (19-81 y/o) 27% incontinent
   d) EMG showed normal strength & timing in both groups for a single PFM contraction, but pulmonary groups had decreased endurance probably due to prolonged bouts of coughing and poor postural strategies prior to cough.
   e) PT intervention to increase endurance and postural strategies for 4 CF & 6 COPD patients: 5 sessions over 3 months. Results: significant reduction in UI episodes (p=.008).

2. *Hodges et al 2007: multiple relationships exist between the trunk, pelvic floor, diaphragm and shoulder muscles in their roles as postural stabilizers during varying upright tasks including standing still and breathing, a fast single prompted UE movement, repetitive fast unilateral arm swing and other tasks.*

C. Adult obesity:

1. *Lambert 2005, Jolly 2014: Pressure related co-morbidities such as gastroesophageal reflux disease, hernias, stress incontinence, diabetes, hypertension, and venous insufficiency showed increased prevalence, especially for obese patients with IAPs of 12 cm H_2O compared to obese patients with IAPs 9 cm H_2O.*
2. *Varela 2009: Morbid obesity causes adverse increase in IAP (intra-abdominal pressure) which has been identified as the likely cause of systemic hypertension.*

III. Internal organs that generate and/or use positive pressure

A. Pulmonary
B. Heart / circulation
C. Gastrointestinal tract
D. Lymphatic system
E. Physiology can drive motor behaviors and may be incorrectly attributed to neurological dysfunction

1. *<u>EXAMPLE:</u> a common infant issue: GI dysfunction with severe reflux & constipation, as well as torticollis and motor delays.*
2. *Constipation can cause reflux (backed up pressures) much like a sewer pipe that is blocked at the exit. Noxious stimulus from the acid reflux stimulates a survival response to avoid the pain, typically trunk extension because it lowers abdominal pressures. Persistent pain from the left side of the abdominal cavity may refine the aversion response to include extension with right trunk rotation, resulting in torticollis. This physiologic torticollis response often includes neck extension rather than neck flexion.*
3. *Severe physiologic driven motor responses like this in response to painful, repeated reflux may include full opisthotonus with torticollis. Diagnosis: <u>Sandifer's Syndrome.</u>*
    a) Possible additional consequences: trunk asymmetry and scoliosis
4. *Postural control patterns may be extension dominant because of repeated pain when moving into flexion. Example, toe walkers may have a significant history of reflux. Repeated noxious stimulus during flexion patterns reinforced reliance on extension strategies (survival response).*
5. *Eye gaze may tend to be upward (reflecting extension pattern)*
    a) may impair bilateral UE manipulation skills
    b) and later, may impair reading skills

IV. Core Muscles

A. New definition of "core" stability

1. *Core stabilization extends from the vocal folds on the top to the pelvic floor on the bottom and includes EVERY muscle in between.*

B. Muscles of Ventilation / Posture: A "Triad" of support

1. *Diaphragm, intercostals and abdominals together provide more biomechanical support for breathing than any of these muscles alone*
2. *<u>Butler 2014</u>: the nervous system recruits inspiratory muscles nonuniformally, likely to strive for minimal metabolic cost for breathing at any particular moment.*
3. *Other significant research: <u>Gandevia 2006, Saboisky 2007, DeTroyer 2009</u>, <u>Schilero 2009</u>, <u>Hudson 2011</u>, <u>Hu 2011</u>, <u>David 2015</u>*

C. Diaphragm

1. *<u>Innervation</u> – phrenic nerve C3-5*
2. *<u>major muscle</u> of passive ventilation, provides ~2/3 to 3/4 of tidal volume (quiet breathing) effort and volume*
3. *<u>primary movement</u> - all 3 planes*
4. *<u>completely separates</u> thoracic and abdominal cavities to regulate pressures*
5. *<u>Boney attachments</u>: anterior at xiphoid process. Anterior, inferior and lateral at ribs 8-10. Posterior via crural legs to lumbar spine.*
6. *<u>additional support</u>: vocal folds and pelvic floor*
7. *<u>dependency on intercostal and abdominal muscles</u> to help the diaphragm generate adequate*

pressure changes between the thoracic (negative pressure) and abdominal (positive pressure) cavities during inhalation

8. *Stability: diaphragm uses the positive pressure of the abdominal cavity to help "stabilize" the central tendon of the diaphragm (primarily inferior expansion).*
9. *Coordinated sequence: with transverse abdominus and pelvic floor muscles for every quiet breath.*
10. *Peripheral fibers of the diaphragm can then use this "stability" to enhance their effectiveness (primarily lateral and superior expansion)*
11. *concentric contractions - quiet and forceful inhalation patterns*
12. *eccentric contractions - controlled exhalation & speech*

D. Intercostals

1. *innervation - T1-T12*
2. *primary function - stabilizes rib cage during inhalation to prevent chestwall from being sucked inward (paradoxical breathing) due to the negative pressure generated in the thoracic cavity*
3. *primary movement - concentric contractions*

    a) lateral & superior expansion in lower chest (both quiet and forceful inhalation), anterior expansion usually least significant component
    b) anterior & superior expansion in upper chest, lateral expansion usually least component
    c) primary rotator of thoracic cage / spine
    d) forceful exhalation - primarily medial and inferior compression in lower chest; posterior and inferior compression in upper chest

4. *eccentric contractions*

    a) slow release of inspiratory muscles needed for controlled exhalation & speech
    b) vocal folds are the "gatekeepers" for thoracic chamber positive pressure regulation; controlling exhalation volume and speed.
    c) Patients with tracheostomies but no speaking valves, cannot perform eccentric thoracic maneuvers because the tracheostomy tube bypasses the vocal folds, thus allowing the air to escape at will.

E. Abdominals

1. *innervation T6 - L1*
2. *external obliques and rectus: stabilizes inferior border of rib cage, covering the false ribs (mid-trunk interfacing). Insertion is on exterior rib cage.*
3. *internal obliques pulls the inferior border of the rib cage downward for trunk stabilization and forceful exhalation maneuvers. Insertion on inferior border of ribs.*
4. *transverse abdominus (TA): significant role in synchronizing pressure changes with the diaphragm for optimal respiratory movements while simultaneously meeting the abdominal pressure needs for postural support. TA is the only abdominal muscle to insert on interior rib cage. It inter-digitates with the diaphragm's insertions on ribs 8-10 forming the superior muscular dome of the abdominal cavity. The pelvic floor muscles form the inferior sling.*
5. *provides visceral support along anterior, lateral and posterior trunk*
6. *provides positive pressure support for the diaphragm*
7. *provides necessary intrathoracic pressure for cough, bowel movements, venous return, etc.*

F. Sequence of a normal quiet breath (tidal volume)

1. *First: easy onset, subtle rise of the upper abdomen*
2. *Second: lateral costal expansion of the lower chest*
3. *Third: gentle rise of the upper chest primarily in the superior and anterior planes*

V. Internal Organs

A. Thoracic Cavity

1. *Trachea & esophagus*

    a) bundled along thoracic spine, thus spinal abnormalities can clinically affect breathing, airway protection and swallowing mechanics
    b) trachea and esophagus are anatomically tied together.
    c) a tracheostomy tube will impair normal tracheal elevation during swallow, thus the presence of a trach tube indicates dysphagia

2. *Aorta*
3. *Lymphatic system*
4. *Heart*
5. *Lungs*
6. *Diaphragm and lower esophageal sphincter*

B. Diaphragm's 3 openings: for the great vessels: aorta, esophagus, inferior vena cava

1. *Aorta*

    a) high pressure system
    b) aorta passes through the diaphragm at its most stable point between the crural legs (posterior attachments to lumbar spine) and is the least affected of the 3 great vessels by the diaphragm's inspiratory excursion

2. *Esophagus*

    a) Low pressure system
    b) passes through diaphragm's crural muscle region, not through the central tendon
    c) the diaphragm couples with the lower esophageal sphincter (LES) to effectively control reflux forces more efficiently than either one alone.

3. *Inferior vena cava*

    a) Low pressure system
    b) passes through the diaphragm's central tendon at the peak of the diaphragm's dome.
    c) The diaphragm has the opposite effect on the IVC compared to the esophagus.
    d) During inhalation, the coupling between the diaphragm and inferior vena cava aids in venous return from the lower body: pressure drops in the vena cava above the diaphragm (negative thoracic pressure) while pressure increases below the diaphragm (positive abdominal pressure). Action is similar to sucking fluid up through a straw.

C. Abdominal Cavity

1. *Stomach and intestines*

    a) inhalation pressure creates a peristaltic like action for the intestines; massaging lower intestines to enhance lower GI motility for elimination.

2. *Other internal organs*
3. *Arteries & veins*
4. *Lymphatic system*

D. Research on the diaphragm and its relationship to other internal systems

1. *Shafik 2004 & 2006*

    a) Illustrated the relationship between crural diaphragm and LES
    b) 17 subjects: tested diaphragm / LES junction under sudden strain (simulated cough) and sustained strain (simulated defecation or urination) conditions while under surgical repair for abdominal hernias unrelated to the esophagus
    c) Crural diaphragm accounted for 44% of the expressed lower esophageal pressure. LES 54%.

2. *Pandolfino 2007 & 2009*

    a) Demonstrated the link between the role of the diaphragm and the LES
    b) High resolution manometry allows for isolation of the crural diaphragm contraction from the LES contraction
    c) 75 controls. 156 GERD patients

        (1) *Strongest association, and the only independent predictor of GERD as an outcome, was impaired crural diaphragm function (less ability to increase lower esophageal pressure (normal 17 mmHg, GERD 10-11 mmHg): ~40% less pressure generated by GERD group.*

3. Nonsurgical treatment of LES incompetence.

    a) *Nobre e Souza 2013: inspiratory muscle training improved LES function and decreased GERD symptoms.*
    b) *Sun 2015: diaphragm biofeedback training decreased GERD symptoms*

4. *Venous return:*

    a) Pinsky 2005, Fasshauer 2014, Uva 2015
    b) Spontaneous breathing off of mechanical ventilation increases venous return due to improve pressure differentials:
    c) Combining a drop in ITP (intra-thoracic pressure) during inhalation with an increase in IAP (intra-abdominal pressure) increases venous return (i.e. straw effect).

E. The Diaphragm: Is it just a respiratory muscle? NO!!!

1. *Multiple simultaneous roles*

    a) Respiratory muscle
    b) Postural control muscle
    c) GI muscle:
        (1) *anti-reflux muscle*
        (2) *lower GI motility muscle*
    d) Venous return muscle

F. Hiatal hernia

1. *The abdominal esophagus, and sometimes the upper part of the stomach, herniate upward into the thorax through the esophageal hiatus because of an impairment at the level of the diaphragm/LES junction.*
2. *The esophagus will always slip superiorly because abdominal pressure is higher than thoracic pressures.*
3. *Symptoms*
    a) GERD
    b) Pain
    c) Increase risk of pulmonary consequences such as non-CF bronchiectasis (McDonnell 2015)

VI. Accessory Support for Breathing and Posture

A. Paraspinals

1. *innervated at T1 - S3*
2. *provides dynamic posterior thoracic stabilization which optimizes normal anterior chest wall movements in three planes.*

B. Pectoralis muscles

1. *innervated C5 - T1*
2. *when used in reverse direction, it provides upper chest anterior and lateral expansion*
3. *can also assist in expiratory maneuvers if the trunk moves into flexion*
4. *can be a substitute rib cage stabilizer following paralysis of the intercostal muscles to prevent paradoxical breathing*

C. Serratus Anterior

1. *innervated C5 - C7*
2. *provides posterior expansion of rib cage when upper extremities are fixated*
    a) can be helpful - i.e. Cystic Fibrosis for specific aeration techniques
    b) can be problematic - i.e. patient with a brain injury may use posterior breathing pattern with no other perceived options. Patient may pull into flexed postures and have difficulty "sitting up straight."
3. *this is the only inspiratory muscles that is paired with trunk flexion movements rather than trunk extension movements*

D. Scalenes

1. *innervated C3 - C8*
2. *provides superior and anterior expansion of the upper chest*
3. *stabilizes upper chest during inhalation even with normal quiet breathing*

E. Sternocleidomastoid

1. *innervated C2 - C3 and Accessory Cranial Nerve*
2. *similar function as scalenes*

F. Trapezius

1. *innervated C2 - C4 and Accessory Cranial Nerve*
2. *provides superior expansion of the upper chest*
3. *least energy efficient accessory muscle. Must lift the weight of entire upper extremity to assist in inhalation*

BREATHING AND POSTURE: A MULTI-SYSTEM EVENT!

Part III: The Vocal Folds

I. Vocal Folds and glottal structures at the "top of the cylinder"

A. "Gate Keeper"

1. *"Gate Keeper" between upper and lower airway*
2. *"Gate Keeper" of pressure support in thoracic cavity, which in turn contributes to IAP support.*

B. Larynx

1. *9 cartilages*
    a) 3 single cartilages: thyroid, cricoid, epiglottis
    b) 3 pairs of cartilage: arytenoids, corniculate, cuneiform
2. *1 bone: hyoid*
3. *2 muscle groups*
    a) extrinsic
    b) intrinsic

C. Protects opening of lower airway to prevent aspiration

1. *Epiglottis: primary protection (penetration)*
2. *Vocal folds: backup protection (aspiration)*

    a) At rest, the "V-shape" vocal fold muscle is partially opened; wider posterior than anterior (neutral glottal opening).
    b) During exercise, the vocal folds are abducted (wider opening) to varying degrees in order to increase inspiratory flows for greater air volume in a shorter period of time in order to meet the increased metabolic needs of exercise.
    c) During speech, the vocal folds are adducted (narrowed glottal opening) to varying degrees in order to restrict expiratory flows for sound production using Bernoulli's Effect (physics).

D. Maintains proper airway opening during inhalation

1. *Entire larynx descends: transverse airway enlarges, dropping airway pressure by at least 3 cm H20 which creates an inspiratory moment.*
2. *Quiet breathing: vocal folds abduct only slightly*
3. *Deep breathing: vocal folds abduct significantly to enlarge opening*
4. *Phonation:*

    a) Regulates tension / position of vocal folds & laryngeal cartilages for optimal voicing
    b) Regulates balance between vocal tension & exhaled airway pressure
    c) Creates sub-glottal pressure with vibration: one of the body's natural airway clearance mechanisms

E. Stabilizes: "Glottal effort closure reflex"

1. *Increases upper extremity (UE) and trunk power and stability through adduction of entire larynx which results in increased thoracic pressure*
2. *Examples: Coughing, yelling, pushing, twisting tight jar lid, tennis serve, bowel evacuation*

F. Research

1. *Hayama 2002*

    a) 4 subjects: Olympic and elite gymnasts. EMG data and fiberoptic endoscope
    b) Air trapping via glottal closure used during heaving loading, i.e. when postural demand on the shoulder musculature exceeded force production by the UE alone.

2. *Eliasz 2004*

    a) During acceleration, Air Force pilots experience an increased gravitational force acting upon their bodies.
    b) Pilots achieve an increase in their tolerance to these forces (G-tolerance) by isometrically contracting their trunk flexors and lower extremities against a closed or partially closed glottis.
    c) The author assessed success of glottal/trunk isometric training by measuring an increase in LE force output on a force plate.
    d) By extrapolation, this concept could be used in PT
        (1) *gait: to measure and account for LE force production at heel strike and stance phase of gait with and without glottal maneuvers.*
        (2) *chestwall collapse: to explain the musculoskeletal deformities of the chest and spine commonly noted in children (and adults) who cannot counteract normal gravitational forces due to impaired activation of intrinsic laryngeal muscles, trunk muscles, and/or leg muscles.*

3. *Hagins 2004*

    a) compared 4 different breathing patterns to force and timing measurements over 75 trials while 11 subjects pulled against an isometric load
    b) significance: greatest isometric load pulled when using a "maximal inspiratory hold" breathing pattern
    c) no difference: amongst the other 3 patterns
    d) conclusion: glottal closure against a full volume of air produced necessary postural stability of diaphragm and trunk to maximize lift potential

4. *Orlikoff 2008*

    a) 20 healthy subjects lifted 4 progressively heavier hand-held weights from 0 – 15 lbs. on outstretched hands while phonating
    b) Vocal fold adduction and subglottal pressures increased as postural demand increased, but voicing continued
    c) Mary's comment: at what weight if any, would postural demand exceed postural control causing breath holding to occur and phonation to cease?

G. Massery et al 2013

1. *Rocky Mountain University DSc Doctoral Dissertation: "The effect of airway control on postural stability"*
2. *12 healthy subjects subjected to gentle forward and backward postural perturbations in upright during 7 voicing/glottal conditions*
3. *Conclusion: glottal modulation plays an active role in postural stability in response to perturbations in stance*

a) Thoracic stability:
- (1) *<u>Least stable</u>: forced open-glottal conditions like a sigh had the greatest thoracic displacement compared to partial (talking or natural breathing) or closed (breath holding) glottal conditions regardless of the direction (backward or forward) of the perturbation*
- (2) *<u>Most stable</u>: static breath-holding maneuvers showed the least thoracic displacement*

b) Center of Pressure (CoP) stability:
- (1) *<u>Least stable</u>: greater CoP displacement occurred with backward perturbations and at either end of glottal modulation (open glottis or closed glottis).*
- (2) *<u>Most stable</u>: the least displacement occurred during partially opened glottal conditions of talking (mid-range control), especially 'counting'*

c) Clinical implications:
- (1) *Our findings may help to explain common clinical breath-holding strategies used by patients with balance impairments. The thorax was indeed more stable, but breath-holding may not afford the dynamic control necessary to efficiently control CoP.*
- (2) *Without the ability to recruit glottal structures as part of dynamic postural control, balance strategies appear inherently disadvantaged. An open glottal condition was not stable for either the thorax or CoP.*
- (3) *Based on our findings, we would anticipate that patients with tracheostomies (forced open-glottal conditions) would show balance impairments. Further study is warranted.*
- (4) *Encouraging patients to talk during balance activities may improve their dynamic postural stability.*

d) EXAMPLE
- (1) *Kevin, TBI secondary to brain tumor. Vent dependent.*

II. Pelvic Floor at the "bottom of the cylinder"

A. <u>Strong muscle support</u> provides functional integrity at the base of the abdominal cavity in spite of constantly fluctuating abdominal pressures

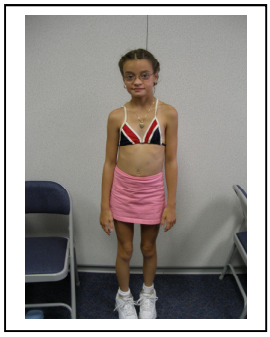
B. <u>Pelvic floor muscles</u> play an important role in:

1. *Completing the internal muscle shell that supports IAP. Diaphragm and transverse abdominis (TA) form the superior dome; the TA forms the lateral walls of the cylinder; the pelvic floor and TA together form the inferior dome.*
2. *preventing incontinence*
3. *supporting dynamic postural stabilization of the lumbar spine during increased postural demand.*
4. *supporting breathing mechanics for both inspiratory and expiratory maneuvers.*
5. *supporting other fluid based pressure related tasks related to circulation, lymphatic drainage, etc.*

C. <u>Breach in pelvic floor</u> may be a result of excessive pressure during forceful expiratory maneuvers such as:

1. *coughing or sneezing, yelling or laughing, pushing, twisting the lid of a tight jar, etc.*

D. EXAMPLE: Arriana



1. *Benign hypotonia, balance impairments, poor breath support for speech, poor endurance*
2. *Chronic constipation (bowel movement every 7 days): major contributor to poor breath support*
3. *backed up lower GI system impaired diaphragm's descent.*
4. *inspiration became more shallow, forcing greater recruitment of accessory muscle breathing which in turn likely was the major reason for her cervical over-stabilization.*
5. *All of which contributed to decreased vocal utterances and clarity when constipated.*

E. Nocturnal enuresis (bed wetting) and sleep disordered breathing (SDB)

1. *Early findings:*

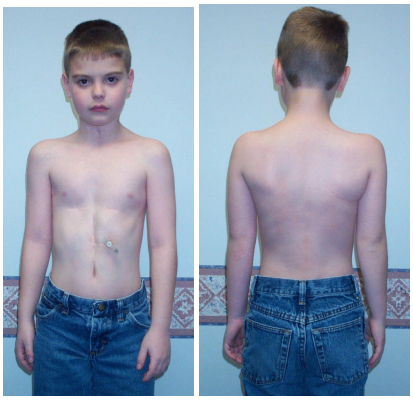
   a) Bascom 2011: SDB, specifically obstructive sleep apnea (OSA), was prevalent in children with nocturnal enuresis especially for those with daytime incontinence (non-monosymptomatic enuresis)

   b) Waleed 2011: 33 of 47 children with nocturnal enuresis were also diagnosed with SDB. SDB decreased with age (5 – 10 y/o). All underwent surgery for airway obstruction. Afterward, 88% (29) improved: 15 were cured of enuresis completely and 12 made significant improvements within 90 days. 2 did not improve nocturnally, but all 29 significantly improved their daytime enuresis.

2. *Re-confirmed: Neveus 2014, Kovacevic 2014 & 2015, Park 2016*

   a) Zaffanello 2017: systematic review. Increased IAP due to OSA (effortful breathing to pull air in around the upper airway obstruction), increased BP, decreased arousal response, and hormonal changes, all contribute to an increased risk of noctural enuresis. Reducing/eliminating OSA and its sequela often resolves nocturnal enuresis. SDB should be considered a major contributor to nocturnal enuresis and should be ruled in/out for each child.

III. Integumentary



A. Adequate mobility of the skin and other connective tissue is necessary for the freedom of the underlying structures to maximize the potential of both chestwall expansion for ventilation as well as postural responses.

1. *Stecco 2011& 2013*

B. Fascial tension contributes to spinal stability

1. *Vleeming 2014: Spinal stability is increased via increased fascial tension of the thoracolumbar fascia (TLF) when the transversus abdominis contracts (improved biomechanical advantage of multifidus)*

C. Fascial restrictions can result in multiple consequential impairments

1. *Clinical Case: Danny 9½ y/o boy with congenital tracheo-esophageal fistula (TEF) and resultant scars on trachea, right lateral rib cage, stomach, abdomen (vertical), anterior chest (horizontal), and multiple other small scars from the likes of chest tubes, etc., causing multiple system impairments as his body matured. (Massery, Linda Crane Lecture 2009)*

IV. Summary

A. The body functions as a whole unit with all the individual systems interacting and supporting one another for both physiologic and physical functions.

B. In particular, postural control and the mechanical support for breathing are inter-dependent, yet breathing needs always takes precedence over postural needs.

C. Trunk control, breathing, and internal functions such as the GI tract, are dependent on the ability of the body to generate, maintain and regulate pressure in the thoracic and abdominal chambers; the control of which extends from the vocal folds down to the pelvic floor.

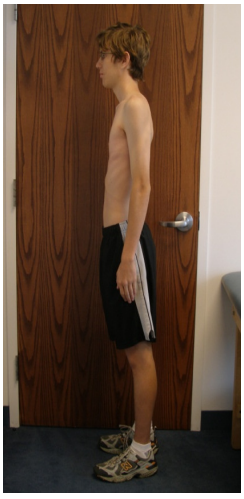
D. Therefore, <u>all</u> body systems that generate or use pressure support for <u>function</u> must be screened for their role in the <u>function or dysfunction</u> of breathing and/or postural control maneuvers.

1. *Musculoskeletal*
2. *Neuromuscular*
3. *Cardiovascular / Pulmonary*
4. *Integumentary*
5. *Internal Organs*

V. Case Report:

1. *<u>Ryan, 16 y/o</u>: congenital pectus excavatum. Is it just a "cosmetic deformity?" No PT or other therapy had been attempted to correct chest deformity / secondary musculoskeletal postural deformities.*
2. *<u>Picture 1</u>: Initial PT evaluation. Ryan demonstrated his 'best' posture.*
3. *<u>Picture 2</u>: 6 months of PT (22 out-patient visits): dramatic improvement in postural alignment and postural control greatly reducing his risk of LBP and/or shoulder impairment.*
4. *<u>Picture 3</u>: post pectus corrective surgery: pectus impaired cardiac function. Surgery was medically necessary. Postural changes continue to show marked improvement. No PT was needed post-surgery.*





Breathing and Postural Control
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NORMAL AND ABNORMAL CHESTWALL DEVELOPMENT AND FUNCTION

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Normal Influences on Chest Wall Development

- Rib cage: 3 dimensions uniquely influenced by:
  - Genetic predisposition
  - Gravity
  - Muscle strength / Muscle tone
  - Work of breathing ("cost of survival")
- Focus of today's lecture
  - Newborn - 3 months old
  - 3 - 6 months old
  - 6 - 12 months old

The Newborn – 3 Months Old

The Newborn – 3 Months Old

- Shape
  - Chest: Coronal Plane:
    - Triangular shape
    - Flat and narrower at the apex
    - Round and wider at the base
  - Trunk: 2 distinct compartments
    - Motor control: thorax and abdomen not yet functioning as a single trunk

Massery 1991, Bastir 2013, Garcia-Martinez 2016

The Newborn – 3 Months Old

- Sagittal view
  - Ribs more horizontally aligned than adult with narrow intercostal spacing
- Trunk proportions
  - small chest, large abdomen
  - Approximate 1:3 ratio chest / abdomen

Newborn Chest Shape: Developmental Advantage

- Shape provides stability !
  - Horizontal ribs / narrow intercostal spacing provides structural stability to rib cage
  - Shape resists gravity's collapsing forces during inhalation's negative pressure
  - Both factors contribute to the transition from in-utero "practice breathing" to out-of-utero independent, anti-gravity breathing

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Newborn Chest Shape: Developmental Advantage

- Opposite from adult rib cage
  - Adult shape: designed to maximize mobility, not stability
  - Adult strength: chest muscles are strong enough to resist gravity and don't need as much structural stability

The Newborn: Breathing Pattern

- No - Accessory muscles
  - SCM
  - Scalenes
  - Pectoralis
  - Intercostals
  - Serratus
  - Limited trapezius
- Yes - Diaphragm
  - Obligatory pattern (brainstem)
  - Primarily a single plane of movement (inferior)
  - Nose breather

The Newborn: Breathing Pattern

- No respiratory reserves
  - Can't take a deeper breath
  - Can't exhale forcefully
  - Fast, variable RR
    - Wertheim 2009: 30 - 65 br/min, mean 43 br/min
- Respiratory stress options
  - Breathe faster
  - Attempt to use accessory muscles

What if the diaphragm is stronger than the rib cage structure?

Video: Hiccups (normal, transient paradoxical breathing)

Gracie, 1 mo old
- Healthy infant

What if the diaphragm is stronger than the rib cage structure?

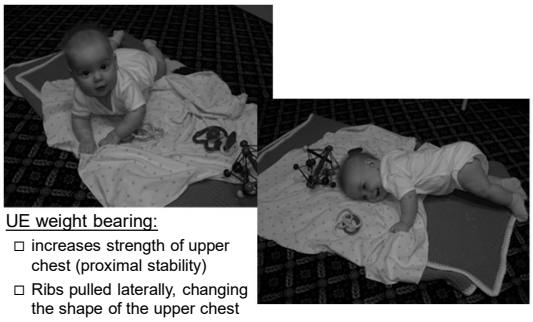
Video:
- Abnormal, persistent, paradoxical breathing (diaphragm excessively dominant)

Declan, 11 mo old
- L-LL lobectomy
- Congenital pectus excavatum
- Low tone
- Motor delays
- Development of scoliosis in infancy

Massery 2012, Fokin 2009

3 - 6 Months

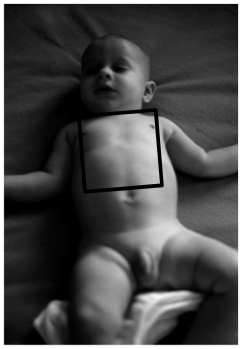
Baby pushups!



- UE weight bearing:
  - increases strength of upper chest (proximal stability)
  - Ribs pulled laterally, changing the shape of the upper chest

3 - 6 Months

- Shape: Anterior view
  - As upper chest gets stronger, the shape becomes more rectangular rather than triangular



Massery 1991, Bastir 2013, Garcia-Martinez 2016

3 - 6 Months: Increased movement against gravity

Trunk proportion still 1:3

6 – 12 Months
Happy Birthday!

6 – 12 Months

- Strength, proximal stability and postural control continue to improve …
- Chest expands in antigravity planes in all postures …
- All contributing to infant's ability to now sit and move while breathing!

Massery 1991, Kyvelidou 2013

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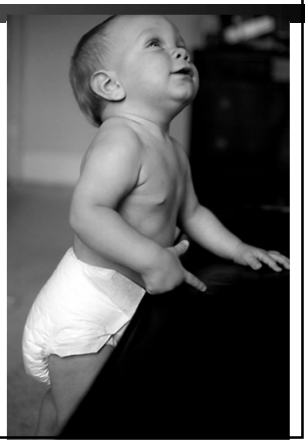
6 – 12 Months

- Baby's constant desire for upright postures (sitting and standing) …
- Results in cervical elongation …
- Making the neck muscles (accessory muscles of breathing) available for respiration as well as turning the head on trunk



6 - 12 Months: Rib cage alignment

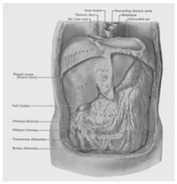
- Downward rotation of ribs
  - Gravity and abdominal muscles pull the ribs downward
    - Abdominal and diaphragm anomalies alter lung, chest and spine development (Panitch 2015, Kassim 2015, Jancelewicz 2013)
  - Longer ribs (inferior) become more downwardly rotated than shorter (superior) ribs
- Separation between ribs
  - Results in increased intercostal spacing
  - Allowing increased intercostal muscle activation and function
- Trunk pressures
  - Adequate IAP & ITP support for upright postures

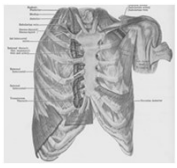
6 - 12 Months: Rib cage alignment

- Trunk proportion: 1:1 (thorax : abdomen)
- Coronal plane: Rectangular shape
- Sagittal plane: Now oval shape rather than round (especially in lower chest)

Breathing and Motor Strategies: 6 –12 months

- Diaphragm
  - Peripheral fibers are pulled inferior as rib cage elongates, increasing dome shape
  - Chest expansion increases in all 3 planes of movement
  - Improved mechanical advantage, reduces RR and work of breathing
- Accessory muscles
  - All accessory muscles now active and available for respiration and postural demands





Breathing and Motor Strategies: 6 –12 months

- Respiration and motor strategies
  - Dynamic stability – breathing and moving simultaneously
  - Efficiency – better support for oxygen demands of gross motor movement, improving motor efficiency and endurance
  - Motor - 6-12 month old babies are in constant motion! Just ask their parents … ☺
    - 3-dimensional movement of trunk, chest, and spine supports …
    - Rolling, sitting, creeping, crawling, standing, walking, climbing …
    - EVERYTHING!

Normal Resting Respiratory Rates (RR)

- As respiratory reserves and lung volumes increase, RR slowly decreases throughout childhood
  - Fleming 2011: Systematic Review of normative RR
  - Findings from 69 studies:
    - RR highly variable in infancy. More homogeneous in adulthood
    - Reported normative data itself is variable between studies.
  - Meta-analysis of normal RR values (reported with 2 SD):
    - Neonate: 35-58 br/min median 44
    - 1 y/o: 29-44 br/min median 37
    - 2 y/o: 23-37 br/min median 30
    - Adult (18y/o): 12-19 br/min median 16

CHEST DEVELOPMENT TRENDS

CHEST	INFANT	ADULT
Size	Occupies 1/3 trunk space	Occupies > 1/2 trunk space
Shape	Coronal: triangular Sagittal: circular, especially lower rib cage	Coronal: rectangular Sagittal: elliptical throughout rib cage
Upper chest	Narrow, flat at apex	Wider, slightly convex at apex
Lower chest	Flared ribs. Abdominals not yet stabilizing false ribs	No flares. Abdominals now stabilizing false ribs
Rib orientation	Horizontal, narrow intercostal spacing (stability)	Downward rotation, wider intercostal spacing (mobility)
Diaphragm	Minimal dome shape, primarily inferior excursion	Marked dome shape, excursion in all 3 planes
Accessory Muscles	Inactive/ineffective at birth. Only trapezius easily accessible	All accessory muscles accessible for breathing

Applying concepts:
Melissa C5 SCI at birth

CLINICAL PROBLEM
MELISSA (3 y/o): BIRTH TRAUMA C5 SCI

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Surviving vs. Thriving

She couldn't breathe in upright!

MELISSA 6 YEARS OLD

MELISSA
6 YEARS OLD

MELISSA 12 YEARS OLD

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MELISSA 12 YEARS OLD

SUMMARY

- Chest wall alignment:
  - Major changes in chest wall shape occur from infancy to adulthood
  - Significant influences: gravity, muscle strength / tone, genetic predisposition, and the work of breathing.
- Breathing strategies and postural control strategies
  - Developed simultaneously to support breathing (surviving) and movement (thriving)
  - Breathing always wins! ☺
- Respiratory and/or breathing mechanics impairments
  - Influence musculoskeletal development, and vice versa, and may be detrimental to the child's health and participation development
- Therefore,
  - Chest wall development must be assessed within the context of motor and health development in order to assess its overall impact on the child's development.

The End

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NORMAL AND ABNORMAL CHEST WALL DEVELOPMENT AND FUNCTION

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WHAT YOU CAN DO IN 90 SECONDS OR LESS THAT HAS A PROFOUND AND LASTING EFFECT? POSITIONING STRATEGIES

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I. UPRIGHT POSTURES

A. What type of breathing pattern do you want to encourage?

1. More diaphragm activation
2. More accessory muscle activation
3. More symmetrical activation

B. How can you get it?

1. Pelvis and mid trunk

a) Anterior tilt - tends to facilitate more upper chest breathing
b) Posterior tilt - tends to facilitate more diaphragm breathing

2. Shoulders/upper extremities

a) Full facilitation of upper accessory muscles: shoulder flexion/abduction/external rotation

b) Full facilitation of diaphragmatic and lower chest muscles: shoulder extension/adduction/internal rotation

c) Subtle changes

(1) scapular retraction/protraction
(2) shoulder flexion/extension
(3) shoulder abduction/adduction
(4) shoulder external/internal rotation
(5) forearm supination/pronation

d) Head & neck alignment

(1) forward head
(2) neutral chin tuck

(a) swallowing
(b) speech

C. How to achieve these alignments with simple adaptations

1. Increased lumbar lordosis increased lung volumes for patients seated in wheelchairs. (**Landers 2003, Lin 2006**)

2. Towel rolls for increase anterior tilt and opened anterior chest wall

b) thoracic vertical roll
c) ischial roll in sitting
d) thoracic horizontal roll
e) lumbar roll

3. Wedges

4. Household furniture

D. Wheelchair considerations

1. Abdominal/trunk support

a) Soft support - abdominal binders

(1) placement - around xiphoid process to iliac crest

(2) how tight? tight enough to support not inhibit diaphragmatic excursion

(3) **Larson 2009** – post abdominal surgery. Binder helped to reduce pain and had a tendency to improve vital capacity, but did not affect length of stay

(4) **Koo 2015** – use of a binder with post-abdominal surgical patients may improve biomechanical support of diaphragm and decrease dyspnea

(5) **Wadsworth 2008 & 2012** – patients with quadriplegic spinal cord injuries wearing an abdominal binder had longer phonation, louder voices and increased pulmonary function

b) Rigid support - body jackets (total contact TLSO)

(1) Full contact TLSO with an abdominal cutout increased FVC and FEV1. (**Frownfelter 2014**)

(2) abdominal cutouts - from xiphoid process to umbilicus

(3) abdominal binder used over opening

2. Lateral trunk supports

3. Head supports

4. Spine supports - lumbar and thoracic

5. Foot placement - effect on pelvis

II. RECLINING POSTURES

A. What kind of breathing pattern do you want to encourage here? Is it different than in upright?

B. Problem-solve the following question in supine. What do you need to do in terms of positioning to encourage these breathing patterns?

Breathing Pattern Desired	Position of the head/neck	Position of the arms	Position of the spine	Position of the legs/pelvis
Diaphragmatic pattern				
Upper accessory muscle pattern				
Symmetrical pattern (hemiplegia)				
Your patient				

C. Sleep considerations

1. What was the patient's pre morbid sleeping posture?

2. What is the most effective breathing pattern for the patient now?

3. How is gravity affecting breathing?

4. Is the patient's preferred posture an option now?

5. Does he/she show signs of sleep disordered breathing such as snoring or stridor?

6. Central sleep disorders such as prolonged periods of apnea or irregular rhythms?

7. Equipment: How do beds or car seats effect breathing? **(Cerar 2009, Shiraishi 2009)**

8. Sleep disordered breathing in pediatrics:

a) may be underlying cause of impaired school performance: cognitively and behaviorally **(Chervin 2006, Halbower 2006, Mulvaney 2006, Constantin 2015).**

b) may be a major contribution to nocturnal enuresis (bed wetting) **(Bascom 2011, Waleed 2011, Zaffanello 2017) .**

9. Sleep disordered breathing in adults**:**

a) SDB present with some adults with ADHD complaining of sleep problems, and should be screened as a co-morbidity (**Surman 2006, Yoon 2012**).

b) Nocturnal GER is prevalent for adults with asthma and OSA (obstructive sleep apnea) and appears likely due to the change in intra-thoracic pressures related to the increased work of breathing (**Teodorescu 2009**).

c) Obesity is a high risk factor for SDB and is associated with cardiac dysfunction, onset of diabetes type 2, and other metabolic impairments (**Cintra 2011, Dixon 2011, Lurie 2011**).

D. What adjustments could you make in positioning to potentially improve your patient's breathing mechanics and/or ventilation-perfusion?

5. Design your intervention strategy for the following positions:

a) Sleep positioning

b) Recumbent positioning

c) Upright positioning

(1) Sitting with back support

(2) Sitting without back support

POSITIONING AND MOVEMENT STRATEGIES

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VENTILATORY OR MOVEMENT STRATEGIES: INTEGRATING NEUROMUSCULAR, MUSCULOSKELETAL, RESPIRATORY & SENSORY SYSTEMS

***Massery**. What's Positioning Got to Do With It? Neurology Report, 1994:18(3):11-14.*
***Frownfelter & Massery**. Facilitating ventilation patterns. Cardiovascular & Pulmonary PT Evidence & Practice, ed. 4, 2006:Chap. 23.*

I. WHAT IS A VENTILATORY OR MOVEMENT STRATEGY?

A. Definition: A ventilatory strategy is the intentional pairing of inhalation & exhalation patterns with movement in order to enhance the overall motor task.

II. CONCEPT DEVELOPMENT:

A. Based on normal motor development, anatomy, physiology, energy efficiency of movement, dual nature of breathing and moving, neuroplasticity, and 30+ years of observations.

B. Research:

1. **Hodges 2007**: postural control, respiration and pelvic floor responses are related

2. **Doidge 2007** (Chapter 3): Mike Merzenich's developmental work on neuroplasticity in the 1980s & 1990s

a) "Neurons that fire together wire together"
b) "Neurons that fire apart wire apart", or "Neurons out of sync fail to link"

3. Efficient recruitment of muscles for respiration and trunk control

a) **Butler 2008** - recruitment of external intercostal muscles for inspiration are highly associated with an increased mechanical advantage (r^2 =0.99). Patterns varied significantly between subjects.

b) **Butler 2014** – Recruitment of respiratory muscles is geared to maximize mechanical advantage (efficiency of contractions) of available muscles. Current hypothesis: intercostals and diaphragm output per breath is integrated at the spinal cord level for quiet, non-voluntary breathing and trunk control. Exciting concept!

c) **Froese 2006** – How you breathe differs by the strength of your diaphragm (3 healthy subjects paralyzed transiently and re-tested). Sidelying: Non-dependent lung moved more efficiently when paralyzed. Dependent lung moved more when healthy. IAP (intra-abdominal pressure) is important.

d) **O'Connell 2014 & 2016** – Grunting (breath control) during tennis serves increases ball velocity, UE force, and peak muscle activity of trunk & serving arm.

III. THE PRINCIPLES FOR VENTILATORY STRATEGIES: INTEGRATING ALL THE BODY SYSTEMS INTO FLUID, EFFICIENT MOVEMENTS

A. **Thoracic spine movements:** coordinated with respiration and determines the appropriate matching phase

1. Extension: usually paired with inhalation (sitting up, reaching up, etc.)
2. Flexion: usually paired with exhalation (squatting, reaching down, etc.)
3. Research: **Lamberg & Hagins 2014**
   a) Reaching up to an object while going onto tiptoes was highly associated with inhalation and increased lung volume.
   b) Coming down was highly associated with exhalation and decreased lung volume.
   c) Breath holding, if it occurred, occurred most frequently during the "hold" phase: of the high-placed object at the peak of the reaching task.
   d) Breath support may be used to increase trunk stability.

B. **Primary type of muscle contraction used during the motor task:** determines specific muscle contraction of the inspiratory or expiratory pattern

1. **Isometric vs. isotonic contraction**
   a) isometric (stability activities)
      (1) paired with breath holding (not valsalva)
      (2) static stability postural strategy: i.e. - reaching up to a high shelf and "fishing" around for something
   b) isotonic (movement activities)
      (1) paired with inhalation or exhalation pattern
      (2) dynamic stability postural strategy: i.e. - any activity that requires movement of the trunk (chest, spine, pelvis) such as standing up, sitting down, reaching, etc.

2. **Concentric vs. eccentric contraction**
   a) Concentric - moving up into gravity
      (1) paired with a concentric breathing pattern; shortening of the muscle
      (2) think of lifting up a barbell. Your bicep muscle contracts concentrically. Apply the same concept to your chest muscles, i.e. all inspiratory patterns, forceful exhalation
   b) Eccentric - coming back into gravity
      (1) paired with eccentric breathing pattern; controlled lengthening of muscle
      (2) think of lowering the barbell. Your bicep muscle contracts eccentrically by slowly lowering the barbell. Apply the same concept to your chest, i.e. speech, singing, humming, purse lip breathing or any controlled expiratory pattern
   c) Passive
      (1) paired with fairly passive, low demand, postural tasks like sitting in a chair, lying on a couch. Little or no effort.
      (2) Adversely, passive exhalation during stand-to-sit will cause inadequate intra-abdominal pressure for trunk control and will result in descent similar to a fall, increasing a fall risk during transfers.

C. From the spine and muscle contraction information, match the breathing and sensory strategy to that specific motor task

1. Breathing Strategies

a) Inhalation: always a concentric contraction

*(1) can be used to **increase thoracic spine extension** via more activation of upper accessory muscles*
*(2) can be used to **maintain a neutral spine** or slight flexion via activation of a more diaphragmatic pattern*

b) Exhalation: can be many types of muscle contractions

*(1) **passive**: used during quiet breathing. Low "postural demand" on trunk muscles*
*(2) **eccentric**: used during quiet, controlled (slow and intentionally prolonged) activities such as speech or other fine motor related activities*
*(3) **concentric**: used to forcefully expel the air such as in coughing, yelling or any resistive activity that requires a concentric contraction of the abdominal muscles (generally more gross motor related activities)*

2. Sensory strategies

a) Eyes: lead the movement

(1) eyes up - usually paired with inhalation

(2) eyes down - usually paired with exhalation

*(3) Research: **Bexander 2005**: relationship of neck movements/amplitude and vision*

(a) Vision and head rotation was indeed linked. Muscle activation of neck rotators increased when vision matched the head movement, enhancing the neck movement response.

(b) Relationship between vision and neck movement was observed in both static tasks and functional movements

b) Auditory: influences muscle recruitment patterns

(1) Louder, faster, higher pitch voices usually facilitates

(a) more upper accessory muscle breathing
(b) more upper thoracic trunk extension
(c) a quicker inspiratory effort
(d) **Polla 2004** – diaphragm is composed of more Type 1 slow twitch fibers whereas the intercostals are composed of more fast twitch Type 2A, 2X & 2B fibers.

(2) Softer, slower, lower pitch voices usually facilitates

(a) more lower chest, diaphragmatic breathing
(b) neutral or slightly flexed trunk
(c) a slower inspiratory effort

II. INCORPORATING CONCEPTS INTO FUNCTIONAL TASKS – EXAMPLES

A. In each of the following typical motor tasks:

1. **Identify:**
    a) The type of thoracic trunk pattern that is prevalent
    b) The type of muscle contraction that is prevalent

2. **Based on this information, add:**
    a) The most logical ventilatory strategy
    b) The most logical sensory stimulus

B. Rolling

1. Rolling with flexion
2. Rolling with extension

C. Reaching

1. Reaching up
2. Coming back down

D. Talking

1. With activities

E. Dressing

1. Shirts
2. Socks

F. Transfers

1. Assumption of standing and return to sitting (standing pivot)
2. Sliding board transfer

G. Eating

H. Weight Lifting: (fallacies of the trade)

Ventilatory strategies: Decision tree

The Movement					
Thoracic Spine Movement	**Flexion** ↓			**Extension** ↓	
Matching Respiratory Phase	Exhalation ↙ ↓ ↘			Inhalation ↓	
Type of muscle contraction needed for that movement	*Concentric*	*Eccentric*	*Passive*	*Concentric* ↙ ↘	
Matching Respiratory Response (ventilatory strategy)	**Forced Exhalation** yelling, coughing, grunting, blowing	**Controlled Exhalation** talking, singing, humming, gentle purse lip breathing	**Passive Exhalation** no effort, no control, simply "letting go"	**Increased Trunk Extension Desired**: upper chest inspiratory effort (trunk extension & more fast twitch muscles)	**Neutral Trunk Desired:** more diaphragmatic & lower chest effort (neutral trunk & more slow twitch muscles)
Matching visual strategy	Eyes down	Eyes down	No preference	Eyes up	Eyes neutral, maybe even down if eyes up recruits upper chest breathing response
Matching audible strategy	Loud, low pitch, forceful, faster cadence voice	Smooth, softer, slower, sustained voice	No preference	Loud, higher pitch, faster cadence	Smooth, softer, slower, sustained voice
***SAMPLE:* Reaching up to medicine cabinet**	-----	-----	-----	**Upper chest Inspiration** - Trunk extension - inhalation - concentric - upper chest breathing strategy - eyes up - loud, fast, high pitch voice &/or sharp audible inspiratory cue;	-----

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1-4 5-47

PUBLICATIONS BY MARY MASSERY, PT, DPT, DSc

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Respiratory Equipment Resources

Information subject to change: a Google-search may be useful
Mary Massery has no financial association with any of the following companies

1. **Custom ordered abdominal binders:** *Kerem Group, an American Sewing Co.:* www.americansewingcompany.com

2. **Ventilatory Muscle Trainers and other respiratory equipment**: *Philips Respironics, Inc.,*
   a. IMT - Inspiratory muscles trainers ("P-Flex" and "Threshold"): http://www.healthcare.philips.com/main/homehealth/respiratory_drug_delivery/thresholdimt/default.wpd
   b. EMT - Expiratory muscle trainers (TheraPEP and other positive expiratory pressure devices)
   c. Peak flow meters and many other types of respiratory support products: http://www.healthcare.philips.com/main/homehealth/respiratory_care/index.wpd

3. **"The Breather" (inspiratory & expiratory muscle trainer in one unit):** *PN Medical,* http://www.pnmedical.com

4. **"Resistex" (expiratory muscle trainer**): *Mercury Medical*, www.mercurymed.com

5. **"Cough Assist" (a.k.a. Mechanical In-Exsufflator Cof-flator)** : *Philips Respironics, Inc.,* http://www.usa.philips.com/healthcare/product/HC1098160/coughassist-t70-ventilator

6. **Airway Clearance Vests**
   a. "The Vest": *Hill-Rom,* www.thevest.com
   b. "Smart Vest" Airway Clearance System: *Electromed, Inc.,* www.electromed.com

7. **"Acapella", "Thera-PEP", and other respiratory equipment**: *Smiths Medical,* www.smiths-medical.com

8. **Aerobika airway clearance device**: *Monaghan Mediccal Corp.* https://www.monaghanmed.com/Aerobika

9. **"Respiratory Blowing Toys"**:
   a. *PDP Products:* http://www.pdppro.com
   b. *Talk Tools*: http://www.talktools.com/products/
   c. (Canada) *FDMT*: http://www.fdmt.ca

10. **Speaking valves**
    a. *Passy-Muir Valves:* www.passy-muir.com
    b. *Tracoe modular, phonation assist:* http://www.tracoe.com/en/products/modular/

11. **"The Frequencer" Acoustical Clearance Device**: Dy-med-so, http://www.dymedso.com

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RE: Joining Mary Massery's Listserve at: Mary-Massery-Clinical-Discussions@yahoogroups.com

Dear Colleagues,

Therapists involved in my courses and clinics have expressed an interest in continuing their "Breathing" discussions long after the course has ended. In that spirit, I have created a Listserve to encourage these conversations. Therapists who have taken my courses, attended my patient clinics, or share a common cardiopulmonary interest, are welcomed to sign up. There is no membership fee.

I hope the Listserve will stimulate vigorous scientific discussions as well as spirited clinical-case discussions. This is not intended as a one-way discussion or as a forum for dispensing medical advice. It is intended for group discussions; I want all members to freely post questions and to answer questions so we all learn from each other. I will join in the discussions when I have time.

Several therapy disciplines and numerous countries will be represented on this Listserve, so please respect each posting. Please indicate your therapy discipline and your city/state or province/country in your responses.

Welcome. Joining is easy.

1. To join, send a blank e-mail to: Mary-Massery-Clinical-Discussions-subscribe@yahoogroups.com
2. You will receive a confirmation message to the email address you used to subscribe.
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I look forward to our discussions!

Sincerely,

Mary Massery

Mary Massery

COURSE EVALUATION
Please Provide Feedback on the Presentation.

Content: **Comments:**

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Overall Presentation: **Comments:**

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Were the handouts & A-V materials valuable? **YES** **NO**

How?

Did the course meet your expectations? **YES** **NO**

How?

What were the course's strengths and weaknesses?

Thank you for your valued input.

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