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

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

II. 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)
III. Clinical problem: Congenital pectus excavatum (sunken chest)

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

IV. 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 mobility at the expense of stability
   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) True Ribs: 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.

   e) 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.

f) 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) snugly 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.

3. **Functional movements - 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) Bony 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
   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 vertebra 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


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

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.
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 H₂O
      (2) Obese adults: IAP 9 – 14 cm H₂O
      (3) Higher BMIs correlated to higher resting IAP
   d) IAP triples in upright (sitting & standing): 16-20 cm H₂O (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 H₂O
(2) Lifting 10 lb. weight: 12 cm H₂O
(3) Lifting 20 lb. weight: 20 cm H₂O
(4) Squatting: 25 cm H₂O
(5) Cough: 80 - 160 cm H₂O or higher
(6) Jumping: 171 cm H₂O

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. Practical Session: 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.


E. Primary muscles involved in generating, maintaining and regulating pressure 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. **tracheostomies**: bypasses vocal folds, thus inability to create sustained positive ITP.
2. **intercostal weakness/paralysis**: collapse of the anterior chest potentially causing a consequential pectus excavatum.
3. **diaphragm weakness/paralysis**: major deficiency in both breathing mechanics and postural stabilization (balance).
4. **abdominal weakness/paralysis**: 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.
5. **paraspinal weakness/paralysis**: 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. **pelvic floor dysfunction**: inadequate ability of muscles to support the positive pressure exerted on the pelvic floor may result in incontinence or prolapse.
7. **other structural changes or motor control changes**: 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. Practical Session – 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**

VI. Take Home Messages

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

B. All the trunk muscles work together to support postural stability as well as to provide simultaneous support for their primary functions such as respiration, limb force production, balance and continence.
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.
      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 - Patients 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 H2O compared to obese patients with IAPs 9 cm H2O (Lambert 2005).

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)
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.

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 H₂O compared to obese patients with IAPs 9 cm H₂O.
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. **EXAMPLE:** 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: Sandifer’s Syndrome.**
   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. **Butler 2014:** the nervous system recruits inspiratory muscles nonuniformally, likely to strive for minimal metabolic cost for breathing at any particular moment.

**C. Diaphragm**

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

   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.

   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:
   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) **Least stable**: 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) **Most stable**: static breath-holding maneuvers showed the least thoracic displacement

b) Center of Pressure (CoP) stability:
   (1) **Least stable**: greater CoP displacement occurred with backward perturbations and at either end of glottal modulation (open glottis or closed glottis).
   (2) **Most stable**: 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. **Strong muscle support** provides functional integrity at the base of the abdominal cavity in spite of constantly fluctuating abdominal pressures

B. **Pelvic floor muscles** play an important role in:
   1. Completing the internal muscle shell that supports IAP. Diaphragm and transverse abdominus (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. **Breach in pelvic floor** 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. Bascom 2011: Sleep disordered breathing, specifically obstructive sleep apnea, was prevalent in children with nocturnal enuresis especially for those with daytime incontinence (non-monosymptomatic enuresis)
2. 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.
3. Other significant research: Neveus 2014, Kovacevic 2014 & 2015

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 chest wall expansion for ventilation as well as postural responses.

1. Stecco 2011 & 2013

B. Fascia contributes to the stability of the spine

1. Vleeming 2014

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

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

V. Case Report:

1. Ryan, 16 y/o: 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.
3. Picture 2: 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. Picture 3: 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

REFERENCES


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