I. The importance of recognizing sex differences
II. The function of the gluteals during running
III. The female runner’s gluteus maximus
IV. The female runner’s gluteus medius
V. Training the gluteals
   1. Endurance training
   2. Strength training
   3. Flexibility training
   4. Gait retraining

I. DIFFERENCES

Alyson McGregor TEDTalk: “A recent Government Accountability study revealed that 80 percent of the drugs withdrawn from the market are due to side effects on women. So let's think about that for a minute. Why are we discovering side effects on women only after a drug has been released to the market? Do you know that it takes years for a drug to go from an idea to being tested on cells in a laboratory, to animal studies, to then clinical trials on humans, finally to go through a regulatory approval process, to be available for your doctor to prescribe to you? Not to mention the millions and billions of dollars of funding it takes to go through that process. So why are we discovering unacceptable side effects on half the population after that has gone through? What's happening?

Well, it turns out that those cells used in that laboratory, they're male cells, and the animals used in the animal studies were male animals, and the clinical trials have been performed almost exclusively on men.

How is it that the male model became our framework for medical research? Let's look at an example that has been popularized in the media, and it has to do with the sleep aid Ambien. Ambien was released on the market over 20 years ago, and since then, hundreds of millions of prescriptions have been written, primarily to women, because women suffer more sleep disorders than men. But just this past year, the Food and Drug Administration recommended cutting the dose in half for women only, because they just realized that women metabolize the drug at a slower rate than men, causing them to wake up in the morning with more of the active drug in their system. And then they're drowsy and they're getting behind the wheel of the car, and they're at risk for motor vehicle accidents. And I can't help but think, as an emergency physician, how many of my patients that I've cared for over the years were involved in a motor vehicle accident that possibly could have been prevented if this type of analysis was performed and acted upon 20 years ago when this drug was first released. How many other things need to be analyzed by gender? What else are we missing?”
II. GLUTEAL FUNCTION


The human gluteus maximus is a distinctive muscle in terms of size, anatomy and function compared to apes and other non-human primates. Results indicate that the gluteus maximus is mostly quiescent with low levels of activity during level and uphill walking, but increases substantially in activity and alters its timing with respect to speed during running. The major functions of the gluteus maximus during running are to control flexion of the trunk on the stance-side and to decelerate the swing leg; contractions of the stance-side gluteus maximus may also help to control flexion of the hip and to extend the thigh. Evidence for when the gluteus maximus became enlarged in human evolution is equivocal, but the muscle's minimal functional role during walking supports the hypothesis that enlargement of the gluteus maximus was likely important in the evolution of hominid running capabilities.

III. MAXIMUS


Twenty healthy male and 20 healthy female runners were participants. Three-dimensional lower extremity kinematics, and gluteus medius and gluteus maximus muscle activation were recorded using motion analysis and electromyography as subjects ran at 3.7 m/s (+/-5%). Comparisons of hip and knee joint kinematic and gluteus muscle activation data were made using independent t-tests (α=0.05). Females ran with 40% greater peak gluteus maximus activation level (P=0.028, effect size=0.79) and 53% greater average activation level (P=0.013, effect size=0.93) than males. Female runners also displayed greater hip adduction (P=.001, effect size=1.20) and knee abduction (P=0.011, effect size=0.87) angles at initial contact, greater hip adduction at peak vertical ground reaction force (P<0.001, effect size=1.31), and less knee internal rotation excursion than males (P=0.035, effect size=0.71). Greater gluteus maximus activation levels during running may predispose females to earlier gluteus maximus fatigue, promoting altered lower extremity running kinematics thought to be associated with the etiology of patellofemoral pain. Gender differences in transverse and frontal plane hip and knee kinematics observed in this study may also contribute to the gender bias for patellofemoral pain among females.


Whole body kinematics of 34 healthy volunteers were recorded along with electromyography of muscles on the right lower limb while each subject walked at 1.2, 1.5, and 1.8m/s and ran at 1.8, 2.7, and 3.6m/s with surface inclinations of 0%, 10%, and 15% grade. Joint angles and muscle activities were compared between genders across each speed-incline condition. Pelvis and lower extremity segment lengths were also measured and compared. Females displayed greater peak hip internal rotation and adduction, as well as gluteus maximus activity for all conditions. Significant interactions (speed-gender, incline-gender) were present for the gluteus
medius and vastus lateralis. Hip adduction during walking was moderately correlated to the ratio of bi-
trochanteric width to leg length.

Our findings indicate **females display greater non-sagittal motion**. Future studies are needed to better
define the relationship of these differences to injury risk.


Gait analysis of 20 men and 20 women recreational runners. Female runners are reported to be more
likely to sustain certain lower extremity injuries compared to their male counterparts. This has been
attributed, in part, to differences in their structure and it has been postulated that these structural
differences may lead to differences in running mechanics.

*Female recreational runners demonstrated a significantly greater peak hip adduction, hip internal
rotation and knee abduction angle compared to men.*

*Female recreational runners also demonstrated significantly greater hip frontal and transverse plane negative work compared to male recreational
runners.*

*Female recreational runners exhibit significantly different lower extremity mechanics in the frontal and
transverse planes at the hip and knee during running compared to male recreational runners.*

Clark BC, Manini TM, Thé DJ, Doldo NA, Ploutz-Snyder LL. Gender differences in skeletal muscle
Jun;94(6):2263-72.

The purposes of this study were 1) to evaluate gender differences in back extensor endurance capacity
during isometric and isotonic muscular contractions, 2) to determine the relation between absolute load
and endurance time, and 3) to compare men \( n = 10, \text{ age } 22.4 +/- 0.69 \text{ (SE) yr} \) and women \( n = 10, \text{ age }
21.7 +/- 1.07 \text{ yr} \) in terms of neuromuscular activation patterns and median frequency (MF) shifts in the
electromyogram (EMG) power spectrum of the lumbar and hip extensor muscles during fatiguing
submaximal isometric trunk extension exercise. Subjects performed isotonic and isometric trunk
extension exercise to muscular failure at 50% of maximum voluntary contraction force. Women
exhibited a longer endurance time than men during the isometric task \( (146.0 +/- 10.9 \text{ vs. } 105.4 +/- 7.9 \text{ s}) \), but there was no difference in endurance performance during the isotonic exercise \( (24.3 +/- 3.4 \text{ vs. } 24.0 +/- 2.8 \text{ repetitions}) \). Absolute load was significantly related to isometric endurance time in the
pooled sample \( (R(2) = 0.34) \) but not when men and women were analyzed separately \( (R(2) = 0.05 \text{ and } 0.04, \text{ respectively}) \). EMG data showed no differences in neuromuscular activation patterns; however,
gender differences in MF shifts were observed. *Women demonstrated a similar fatigability in the biceps
femoris and lumbar extensors, whereas in men, the fatigability was more pronounced in the lumbar
musculature than in the biceps femoris.*

Lieberman DE, Raichlen DA, Pontzer H, Bramble DM, Cutright-Smith E. The human gluteus maximus and

The human gluteus maximus is a distinctive muscle in terms of size, anatomy and function compared to
apes and other non-human primates. Here we employ electromyographic and kinematic analyses of
human subjects to test the hypothesis that the human gluteus maximus plays a more important role in
running than walking. The results indicate that the gluteus maximus is mostly quiescent with low levels
of activity during level and uphill walking, but increases substantially in activity and alters its timing with respect to speed during running. The major functions of the gluteus maximus during running are to control flexion of the trunk on the stance-side and to decelerate the swing leg; contractions of the stance-side gluteus maximus may also help to control flexion of the hip and to extend the thigh. Evidence for when the gluteus maximus became enlarged in human evolution is equivocal, but the muscle's minimal functional role during walking supports the hypothesis that enlargement of the gluteus maximus was likely important in the evolution of hominid running capabilities.

IV. MEDIUS


Eleven female and 11 male runners participated in this study. Three-dimensional marker positions were recorded with a motion analysis system while the subjects ran along a 25 m runway at a speed of 3.5 m/s. Kinematic variables were analyzed for the stance phase of the right leg. Female runners demonstrated significantly greater peak knee abduction (P<0.05), hip adduction (P<0.01) and internal rotation (P<0.05), whereas male runners demonstrated significantly greater peak rearfoot eversion (P<0.01). The knee abduction angles were positively correlated with hip abduction angles (r=0.49, P<0.05) and negatively correlated with rearfoot eversion (r=-0.69, P<0.001). There was no significant difference in normalised step width between genders (P>0.05). Smaller rearfoot eversion and greater hip adduction related closely to the greater knee abduction as the distal and proximal factors, respectively. These relationships are thought to be the compensatory joint motions in the frontal plane, because there was no significant difference in the normalised step width between females and males.

The current results suggest that if the step width is identical, the subjects with greater knee abduction had smaller rearfoot eversion to compensate for greater hip adduction, which were more apparent in females. This explains greater knee abduction found in female runners, which can be linked to a high risk of knee injury.


Eighty recreational athletes were equally divided into four groups: female PFPS, female controls, male PFPS, and male controls. Trunk, pelvis, hip, and knee frontal plane kinematics and activation of the gluteus medius were evaluated at 15°, 30°, 45°, and 60° of knee flexion during the downward and upward phases of the stepping task. Isometric hip abductor torque was also evaluated.

Females showed increased hip adduction and knee abduction at all knee flexion angles, greater ipsilateral trunk lean and contralateral pelvic drop from 60° of knee flexion till the end of the stepping task (P = 0.027-0.001), diminished hip abductor torque (P < 0.001), and increased gluteus medius activation than males (P = 0.008-0.001). PFPS subjects presented increased knee abduction at all the angles evaluated; greater trunk, pelvis, and hip motion from 45° of knee flexion of the downward phase till the end of the maneuver; and diminished gluteus medius activation at 60° of knee flexion, compared with controls (P = 0.034-0.001). Females with PFPS showed lower hip abductor torque compared with the other groups.

Females presented with altered frontal plane biomechanics that may predispose them to knee injury. PFPS subjects showed frontal plane biomechanics that could increase the lateral patellofemoral joint
stress at all the angles evaluated and could increase even more from 45° of knee flexion in the downward phase until the end of the maneuver. Hip abductor strengthening and motor control training should be considered when treating females with PFPS.


Gluteal tendinopathy is now believed to be the primary local source of lateral hip pain, or greater trochanteric pain syndrome, previously referred to as trochanteric bursitis. This condition is prevalent, particularly among postmenopausal women, and has a considerable negative influence on quality of life. Improved prognosis and outcomes in the future for those with gluteal tendinopathy will be underpinned by advances in diagnostic testing, a clearer understanding of risk factors and comorbidities, and evidence-based management programs.

**V.1. ENDURANCE TRAINING**

Gluteal Endurance Measures (GEMs)

1. Endurance Abduction: The subject is sidelying with his or her back parallel to and lightly touching a wall for spatial reference. The hip and knee of the top lower extremity (the extremity being tested) are in 0° of flexion and rotation, resting on the bottom lower extremity. The bottom extremity’s knee is flexed to 90°, and its hip is flexed near 45° to allow the sole of the foot to rest on the posterior wall. The hand of the top arm rests lightly on the top iliac crest for pelvic monitoring. The bottom arm rests in a relaxed, comfortable position, and the subject’s head rests on a standard pillow with his or her trunk in a neutral position. The subject is instructed to actively abduct the uppermost lower extremity to 30° as measured by the tester using an inclinometer. The subject is instructed to maintain the hip in 30° of abduction as long as possible. The tester is allowed to give cues to the subject during testing to re-achieve correct positioning; however, no motivational cues are given aside from the subject being
advised to continue the test as long as possible before the assessment begins. The tester monitors the subject’s position using a tape marker placed on the wall near the subject’s raised heel until the test ends. The subject is not told or able to see the time elapsed during testing. The test ends when the subject is unable to maintain the test position. The time to task failure is recorded. Average: 2 minutes

2. Endurance Bridging: The subject is hooklying near a wall with his or her arms across the chest. The tested extremity’s knee is flexed to 135° or as near to that position as able. The feet are placed on the ground next to each other near the body’s midline. Shoes are worn. The non-tested extremity’s knee is extended to 0° of flexion, and its thigh is held parallel to the tested extremity’s thigh throughout the test by the subject. The subject is instructed to actively extend the tested extremity’s hip to 0° of flexion as measured by the tester using a goniometer. The subject is instructed to maintain the hip in 0° of flexion as long as possible. The tester is allowed to give cues to the subject during testing to re-achieve correct positioning; however, no motivational cues are given aside from the subject being advised to continue the test as long as possible before the assessment begins. The tester monitors the subject’s position using a goniometer and a tape marker placed on the wall near the subject’s raised pelvis until the test ends. The subject is not told or able to see the time elapsed during testing. The test ends when the subject is unable to maintain the test position. The time to task failure is recorded. Average: 1.5 minutes

V.2. STRENGTH TRAINING

The gluteus medius and maximus comprise about 33% of the muscle mass around the hip (10% and 23%, respectively). A common thought is that their primary functions are for power and strength. A look at the gluteals’ fiber composition, however, reveals they have a larger percentage of Type I fibers than Type II. Research reveals that gluteal endurance, strength, and power assessments are not highly correlated. Therefore, it is recommended the strength and endurance capacity of the gluteals be tested and trained separately.

One study showed the hamstrings were more active and potentially limiting compared to the gluteals in the traditional bridge position with the knee bent to 90 degrees. The simple change of increasing the knee bend to 135 degrees (right figure) caused the gluteals to become TWICE as active as the hamstrings.

These three exercises combine for a prone progression of hip strengthening exercises. Patients are encouraged to contract their core muscles and not hold their breath during the exercises. Patients may perform the prone plank on their knees for an easier exercise. Strap weights may be added to the distal femur for further strengthening. The exercises may be performed as repetitions or held until fatigue. Therapists can monitor for normal breathing and neutral trunk positioning. Significant hip flexor activity is required during these exercises.
The above sidelying progression requires close monitoring of trunk posture. The significant variability in gluteus medius activation, for example, during sidelying abduction may be due to small changes in trunk position. Even a 5-degree backwards movement of the pelvis has been shown to significantly reduce gluteus medius activity. Patients are encouraged to contract their core muscles and not hold their breath during the exercises. The exercises may be performed as repetitions or held until fatigue. During the clam, increasing the degree of hip flexion to 60 degrees slightly increases gluteus maximus activity and slightly decreases gluteus medius activity. In some studies, the side plank is performed with the top foot directly on the bottom foot. During the side plank with abduction, the bottom limb’s gluteus medius activates most, although both are highly recruited. The last two exercises may be limited by shoulder fatigue or discomfort.
The gluteal squeeze is the most convenient glute exercise. It can be done sitting and standing too, and recruits high glute activity. It can be performed with abdominal contraction. The bilateral bridge is a low-level gluteal exercise needed by many as a starting point. It may also help stretch tight hip flexors. The traditional single-leg bridge with the knee at 90 degrees biases the hamstrings while also activating the gluteals. To preferentially activate the gluteals, position the knee closer to 135 degrees of flexion.
The standing exercises above obviously challenge all muscles of the lower limb. The mini squat is a good starting point for weight-bearing strengthening. The lunge is a versatile exercise. It can be performed forward, backward, laterally, with a band, etc. The single-leg deadlift challenges balance while also promoting hip strengthening. The single-leg squat is one of the most demanding exercises for the lower limb. Patients should avoid medial knee collapse to ensure optimal strengthening and enforce good biomechanical habits.
The strengthening exercises to follow are listed according to the general muscle actions they facilitate. They are arranged from generally least to most challenging.

**HIP FLEXION STRENGTHENING**

- Active-assistive heel slides
- Heel slides
- Hooklying marches
- Quadruped knee to elbow
- Seated marches
- Eccentric lowering after seated marching
- Marching on Swiss ball
- Marches with ankle weights
- Standing marching
- Hurdle walks
- Supine straight leg raise, unilateral or bilateral
- Bridging with the contralateral limb extended
- Toy soldiers
- Spidermans/Spiderwomans
- Step-up thrusts
- Isometric hip flexion with a strap or table resistance
- Standing hip flexion with Theraband
- Forward monster walks with Theraband
- Mountain climbers with sliders
- High knee running in place
- Swiss ball pikes

**HIP EXTENSION STRENGTHENING**

- Gluteal squeeze
- Standing hip extension w/ & w/o Theraband
- Prone extension
- Prone extension with abduction
- Quadruped donkey kick
- Bridging
- Step-ups
- Mini-squats
- Backwards monster walks
- Single-leg bridging
- Single-leg bridging on ball with hamstring curls
- Lunges in all directions
- Forward lunge against sport cord
- Single-leg squat
- Single-leg deadlift
- Split squat
# Hip Abduction Strengthening

- Seated clams
- Supine abduction (isometric or isotonic)
- Standing abduction w/ & w/o Theraband
- Hip hikes
- Sidelying abduction
- Clams w/ & w/o Theraband
- Clams with floating foot
- Fire hydrants
- Monster walks
- Side step-downs
- Wall squat
- Lunges in all directions
- Lateral band walks
- Single-leg squat
- Side planks w/ & w/o upper leg abduction
- Ski jumps

# Hip Adduction Strengthening

- Isometric adduction in supine
- Hooklying or supine ball squeeze
- Standing adduction w/ & w/o Theraband
- Standing D1 flexion w/ & w/o Theraband
- Sidelying adduction w/ & w/o Theraband
- Forward and lateral step-ups
- Wall squats with ball squeeze
- Mini-squats with ball squeeze
- Wide-based squats
- Unilateral squats
- Karaoke with ankle weights
- Jumping jacks
- Plank jacks
- Standing leg slide

# Hip External Rotation Strengthening

- Standing knee on stool ER (stool turns)
- Seated ER w/ & w/o Theraband
- Standing D1 flexion w/ & w/o Theraband
- Isometric standing ER against wall
- Sidelying bottom leg ER (pretzel)
- Fire hydrants
- Double- and single-leg squat
- Sumo squat
- Monster walks with Theraband around feet
Tree pose in standing w/ & w/o Theraband
Clams w/ & w/o floating foot

**HIP INTERNAL ROTATION STRENGTHENING**

Standing knee on stool IR (stool turns)
Seated IR w/ & w/o Theraband
Standing D1 extension w/ & w/o Theraband
Reverse clam
Prone IR with Theraband
Isometric standing IR against wall
Double- and single-leg squat

**MULTI-DIRECTIONAL HIP STRENGTHENING**

3-way lunges
Line jumps
Box jumps
Jump-turn squats
Split squats
Single-leg squats
Single-leg deadlifts
Cross-stabilization
Unilateral balance w/ & w/o perturbation or unstable surface
Hopping
Bird dogs
Fire hydrants
Scissor abs
Burpees
Squat with kicks
Donkey kicks
Lunges
Super skaters
Squat jacks
Jump rope
Speed ladder
V.3. FLEXIBILITY TRAINING


Using a modified Thomas Test, female soccer athletes were assigned to a restricted (>0 ° of sagittal plane hip motion above the horizontal; n=20, age=19.9 ± 1 years, ht=167.1 ± 6.4 cm, mass=64.7 ± 8.2kg) or normal (>15 ° of sagittal plane hip motion below horizontal; n=20, age=19.4 ± 1 years, ht=167.2 ± 5.5 cm, mass=61.2 ± 8.6 kg) hip flexor muscle length group. Surface electromyographic (sEMG) activity of the gluteus maximus and biceps femoris, and net internal hip and knee extension moments were measured between groups during a double-leg squat. Isometric gluteus maximus strength was assessed using handheld dynamometry.

**Individuals with restricted hip flexor muscle length demonstrated less gluteus maximus activation (p=0.008)**


HIP STRETCHING EXERCISES

**HIP FLEXION STRETCHING**

Single- or Double-knee-to-chest
Straight-leg raise variations
Standing forward lunge (for front leg)
Standing toe-touch
Standing hamstring stretch with LE on table or heel on chair (starting with or without knee flexion)
Leg swings
Toy soldiers
Total gym
### HIP EXTENSION STRETCHING

- Supine leg hang / Thomas stretch (one leg off the side of the table), flexing contralateral hip
- Half-kneeling forward lunge
- Standing quadriceps stretch
- Standing forward lunge (for back leg)
- Prone rectus femoris stretch (with or without bolster under distal femur)
- Prone press-ups (on elbows or hands)
- Bridging

### HIP ABDUCTION STRETCHING

- Supine bent-knee fallouts
- Happy baby pose
- Side lunge
- Butterfly stretch
- Seated V with side reach

### HIP ADDUCTION STRETCHING

- Standing cross-over IT band stretch (with or without wall support)
- Sidelying leg hang (top leg falling behind bottom leg)
- Supine straight leg cross-over

### HIP EXTERNAL ROTATION STRETCHING

- FABER (Figure-4 stretch)
- Clamshells
- Supine leg rolls
- Pigeon pose

### HIP INTERNAL ROTATION STRETCHING

- Prone fall-outs
- Supine IR with contralateral LE overpressure
- Supine knee cross-over (knee to contralateral shoulder)
- Reverse clamshells
- Side-sitting
- LE D1 extension or D2 flexion (with or without contract-relax technique)
- W-sitting (starting from quadruped with some degree of hip IR)
- Standing walking clock (literally walking around planted LE)
V.4. GAIT RETRAINING


Two female runners with chronic patellofemoral pain underwent 8 sessions of mirror gait retraining during treadmill running. Subjective measures and hip abductor strength were recorded at baseline and after the retraining phase. Changes in hip mechanics and electromyography data of the gluteus medius during treadmill running and step ascent were also assessed. Both runners reported improvements in pain and function that were maintained for at least 3 months. During running, peak contralateral pelvic drop (baseline-postretraining difference: runner 1, 2.6° less; runner 2, 1.7° less) and peak hip adduction (baseline-postretraining difference: runner 1, 5.2° less; runner 2, 6.3° less) were reduced after retraining. Kinematic reductions accompanied earlier activation of the gluteus medius relative to foot strike (baseline-postretraining difference: runner 1, 12.6 milliseconds earlier; runner 2, 37.3 milliseconds earlier) and longer duration of gluteus medius activity (runner 1, 55.8 milliseconds longer; runner 2, 44.4 milliseconds longer). Runner 1 transferred reduced contralateral pelvic drop to step ascent, whereas runner 2 did not (contralateral pelvic drop baseline-postretraining difference: runner 1, 3.6° less; runner 2, 1.5° more; hip adduction baseline-postretraining difference: runner 1, 3.0° less; runner 2, 0.5° more). Both runners demonstrated earlier onset of gluteus medius activity during step ascent (baseline-postretraining difference: runner 1, 48.0 milliseconds earlier; runner 2, 28.3 milliseconds earlier), but only runner 1 demonstrated longer activation duration (runner 1, 25.0 milliseconds longer; runner 2, 69.4 milliseconds shorter). While changes in hip mechanics and gluteus medius activity during running were consistent with those noted during step ascent for runner 1, runner 2 failed to demonstrate similar consistency between the tasks. Earlier onset and longer duration of gluteus medius activity may have been necessary to alter step mechanics for runner 2.
Thoracic Spine, Rib Cage, and Diaphragm

I. Thoracic Spine Anatomy
   a. Comprised 50% of the spine
   b. The rigidity of the thorax provides 3 functions:
      i. Stable base for muscles
      ii. Protection for intrathoracic organs
      iii. Mechanical bellows for breathing
   c. Intimately related to the rib cage
   d. Thoracic spine assumes major importance in providing optimal functional capacity for respiration and circulation
   e. Thoracic Motion
      i. Total sagittal plane motion (flex/ext) – 50-70 degrees
      ii. Horizontal plane motion (rotation) – 30 degrees each side
      iii. Frontal plane (lateral flex) – 25 degrees to each side

II. Anatomy of the Rib Cage
   a. Main goal is to protect the heart and lungs
   b. Inherently stable by design but should have some movement to allow for chest expansion
   c. Rib articulations include 48 additional mobile segments!!
   d. Common Rib Movements
      i. Pump Handle - anterior & superior movement of ribs 1 - 6 and sternum
      ii. Bucket Handle - outward, upward & lateral movement of ribs 7 - 10
      iii. Caliper Handle - posterior and outward movement of ribs 11 - 12
      iv. External and Internal Torsion with Trunk Rotation
   e. Important muscles that attach to rib cage
      i. SCM – indirectly by way of sternum (elevation of sternum will elevate anterior ribs)
      ii. Scalenes – important for 1st and 2nd rib and breathing dysfunction
      iii. Pectoralis Major – elevates upper ribs
      iv. Pectoralis Minor – assists with inspiration
      v. Serratus Anterior - Lower fibers elevate ribs 5 – 9; upper fibers depress ribs 1-4
      vi. External and Internal Obliques – depress lower ribs; elevate diaphragm
      vii. External and Internal Intercostals – elevates ribs
   
   viii. Diaphragm
      1. Primary Muscle of Respiration – 70-80% of inspiration force
      2. Increases longitudinal dimension of the thoracic spine
      3. Indirectly elevates ribs

III. Autonomic Nervous System
   a. Sympathetic Chain Ganglion housed in the thoracic spine
      i. Soma and viscera above diaphragm originate in first 4-5 segments of thoracic cord
      ii. Viscera and soma below diaphragm receive sympathetic nerve fibers from cord below T5
b. When stimulated, possible responses include:
   i. Accelerated heartbeat
   ii. Bronchial dilation
   iii. Secretion of adrenaline and non-adrenaline
   iv. Inhibits bladder contraction

IV. The effects of structural deformities
   a. Scoliosis
      i. Lung capacities and volumes reduced
      ii. Chest expansion decreased
      iii. Asymmetric chest cage motion
      iv. Decreased thoracic spine movement during breathing

   b. Hyperkyphosis
      i. More likely to have difficulty with functional activities (bending, sit-stand, walking, climbing)
      ii. May alter fundamental characteristics of balance (body sway, gait unsteadiness)
      iii. Associated with dyspnea and ventilatory dysfunction or the obstructive and restrictive types
      iv. Vital capacity, inspiratory capacity, total lung capacity, lateral expansion of the thorax are decreased in osteoporotic women with increased kyphosis angle

V. Kinematics of the Thorax during deep breathing
   a. Rib cage moves laterally, vertically, and in an A-P direction – more movement in vertical and AP directions
   b. Symmetric chest cage expansion
   c. Larger upper chest cage movement (~16.7-28.6 mm) vs middle (13.7 - 24.4 mm) vs lower chest cage (4.9 – 13.8mm)
   d. Thoracic spine moves upward and posterior (more movement in upper to middle levels)
      i. Upwards motion ~19 mm
      ii. Posteriorly ~27 mm
      iii. This creates a straightening of natural kyphosis

VI. Kinematics of the Thorax during running
   a. Greater amount of rotation vs lumbar spine
   b. Small amounts of lateral bending (usually coupled with rotation)
   c. Less sagittal plane motion than lumbar spine
   d. Position of the Thorax changes with variations in speed
   e. Position also changes with terrain (uphill vs downhill)
   f. Running effects on disc height

| Table 4. Spinal Motion in Normal Subjects (n = 20) and Scoliotics (n = 41) |
|-----------------|-----------------|-----------------|
|                 | Normal          | Scoliotics      | P    |
| C7              | 19.1 (4.1)      | 7.3 (2.4)       | < 0.001 |
| T3              | 10.3 (2.3)      | 4.4 (1.5)       | < 0.003 |
| T7              | 4.9 (1.8)       | 2.4 (1.3)       | < 0.002 |
|                 | Normal          | Scoliotics      | P    |
|                 | 26.8 (5.6)      | 19.9 (7.6)      | < 0.001 |
|                 | 16.4 (4.2)      | 13.1 (5.3)      | < 0.01  |

Y = vertical motions; Z = A-P motions.
Values are mean (SD).
VII. Runner’s Stitch
   a. Exercise related transient abdominal pain (ETAP)
   b. Can be reproduced with palpation of spinal segments (T8-12)

VIII. Respiratory Diaphragm
   a. Diaphragmatic dysfunction can cause neck, low back, and SIJ pain
   b. Can cause decreased respiratory excursion and inadequate proprioceptive function
   c. People with LBO had high degree of diaphragm fatigue when exposed to overwhelming activities
   d. Plays a role in stabilization through fascial system
   e. Respiratory re-education alter breathing patterns and increase chest expansion

IX. Effects of Manual Therapy on pulmonary function
   a. Rib mobilizations increase FVC, FEV1 and chest expansion
   b. HVLA to the rib cage increase vital lung capacity (chest expansion during forced inspiration and tissue oxygenation)
   c. Single thrust manipulation to the thoracic spine of healthy subjects causes a significant enhancement in chest wall expansion and lung function values
   d. Compared (1) thoracic mobilization vs (2) self-stretching vs (3) mobilization + stretching
      i. Improvements seen in all groups
      ii. TJM+SSE experienced the largest improvement in forced vital capacity (FVC) at 6 weeks, forced expiratory velocity at 1 second (FEV1) at 4 and 6 weeks, and peak expiratory velocity (PEF) at 6 weeks

X. Effects of Exercise on Pulmonary function
   a. 6 week stretching and respiratory exercise program for community-dwelling older adults lead to statistically significant increases in chest wall excursion, 6-minute walk time, and physical performance test scores
   b. Exercise focusing on thoracic mobility and stretching produced improvements in pain, chest expansion, functional capacity, disease activity, pulmonary function parameters and 6MWD test
   c. Runners and people who practiced yoga had improved lung function when compared to sedentary people – “Yogi’s” demonstrated better Peak Expiratory Flow Rate when compared to runners
Manual Interventions for Thoracic and Rib Mobility

Thoracic Rotation in Sitting

Thoracic Extension in Sitting

Rib Mobilization in Sitting

Rib Rolling
Caudal Glides in Side lying

1st Rib Traction

1st Rib Muscle Energy Technique

Thoracic Spine HVLA Thrust Manipulations
Self-Stretching/Mobility Exercises

1st rib with Towel

Reach and Roll

Windmill
Thoracic Extension over Foam Roll

Pec Stretch on Foam Roll

Pec Stretch in Doorway
**Strengthening/Re-training exercises**

**Quadruped Resisted Reach Through**

![Exercise Image](image1)

**Face Pulls**

![Exercise Image](image2)

**Moto Row**

![Exercise Image](image3)
Mid Row

Pulley Punch
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Single Arm Row

Side plank with rotation

High plank with UE driver
Lunge with rotation
References


Abdominal Influence

I. Functional Anatomy/Biomechanics Review
   a. Four layers of muscles functionally positioned in three planes; architecture and morphology determine their function.
      i. **Rectus Abdominus:**
         - *o:* pubic crest and symphysis
         - *i:* costal cartilages of 5,6,7 ribs, xiphoid process
         Global mobilizer – generate torque to produce motion, concentric, direction-dependent activity
      ii. **External Oblique:**
         - *o:* external: lower 8 ribs, interdigitating with serratus anterior/ latissimus dorsi
         - *i:* linea alba, tendinous raphe extending from xiphoid, iliac crest
         Global stabilizer – control ROM, eccentric, direction-dependent activity
      iii. **Internal Oblique:**
         - *o:* inguinal ligament, iliac crest, thoracolumbar fascia inferior to L3
         - *i:* with transversus abdominus into crest of pubis, pectineal line, linea alba, 7 – 10 ribs at costochondral joints
         Global stabilizer – control ROM, rotation
      iv. **Transverse Abdominus:**
         - *o:* lower 6 ribs, Diaphragm, thoracolumbar fascia, iliac crest, inguinal ligament
         - *i:* linea alba, pubic crest
         Fibers oriented different: superior: lay superomedially; middle/inferior: lay inferomedially
         Local stabilizer – each portion has specific function: superior: stabilizes rib cage; middle: spinal stability; inferior: pelvic stability, isometric, increases intraabdominal pressure, transfers power, proprioception
   b. Abdominals work as a group – form a hoop with thoracolumbar fascia to provide functional stability
   c. Abdominals work as torque converters – stimulated by gravity, GRF, momentum, anticipation of loading and/or movement
      i. Example: quick shoulder extension:
         
         LE→TA→RA→OI→Deltoid→OE→MF

         *in individuals with LBP, TA activation is delayed (Hodges & Richardson)*
II. Abdominals and Running
   a. During running the abdominals control motion of pelvis and ribs in 3D; all are important and need to work in synchrony. Coordinated effort with other core mm.
   b. Abdominals react to motion between pelvis and rib cage and works to maintain upright posture
      i. Reciprocal arm swing:
         i. Serape effect- in ballistic actions, mm transfer internal forces from a large section of body – relationship between the hip and contralateral shoulder
         ii. To run efficiently and smoothly – the trunk mm most stabilize the upper body from the moments and reaction forces of the lower limb (Dintiman & Ward, 2003)
      ii. Pelvic control
         i. right foot step: pelvis anteriorly rotates (sagittal plane); lateral tilts (frontal plane); rotates forward (transverse plane)
   c. Important for pelvic floor support
   d. What limits abdominal recruitment
      i. Poor posture
      ii. Limited hip extension
      iii. Limited thoracic motion
      iv. Poor pelvic floor activation

III. Assessment
   a. What is our goal?
      i. Muscle strength/endurance
      ii. Muscle recruitment
      iii. Postural control
      iv. Motor control
   b. Considerations
      i. Gravity
      ii. Plane of movement
      iii. Function
   c. Quadruped opposite arm and leg lift
      i. Increase in lumbar spine lordosis/pelvic tilting
      ii. Unilateral hip hiking
   d. Lunge analyses
      i. Anterior
      ii. Posterior
      iii. Lateral
e. Single leg balance with trunk reaches
f. Running Analysis
   i. Excessive movement of the head, rounded shoulders
   ii. Wide arms or excessive arm swing may indicate trunk weakness.
   iii. Increased impact loading
   iv. Increased trunk rotation
   v. Increased lateral tilt during stance
   vi. Increased anterior tilt during stance

IV. Training
a. Does core training effect running performance?
   i. Sato & Mokha – 6 weeks of core training enhanced 5k time, did not improve running kinetics or SEBT scores.
   ii. Stanton et al. - 6 week Swiss Ball training – core stability/running economy
   iii. Behm et al. - high activation of lower abdominals with moderate to high-intensity running
   iv. Conclusion- injury prevention, symmetry
b. Progress from neuromotor → stability → dynamic
c. Neuromotor Phase
   i. Some supine and prone exercises for abdominals can create excessive compressive and shear forces (McGill, 2001)
   ii. When abdominal mm work in isolation, they bend the spine forward and flex it or twist it to one side (Gray Cook)
   iii. Exercise Examples
      i. Abdominal bracing (TA, multifidi, IO, EO)
      ii. Diaphragmatic breathing
d. Stability Phase
   i. Various positions, ultimately in standing
   ii. Exercise Examples
      i. Planks with leg lift
      ii. Hands and Knee lifts
      iii. Tick tock
      iv. Surfer toss
e. Dynamic Phase – decrease emphasis on abdominal bracing, emphasis on stable and controlled mobility throughout the ROM
   i. Functional exercises – coordination of all parts!!
   ii. Examples
      i. PNF Chops/Lifts – 3D spine motion
         1. Seated
         2. ½ kneeling
         3. Full kneeling
4. Standing
5. Single leg standing

iii. Running Gait Re-training
iv. Dosage – long distance running is endurance event, we need to dose appropriately for that.

Planks with leg lift

Tick Tock

Surfer Toss

PNF Chop
References


Gray G. wwwGrayInstitute.com


Influence of Pelvic Floor with Running
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Objectives
1. Understand basic anatomy of pelvic floor bony and soft tissues structures.
2. Understand basic biomechanics of pelvic floor.
3. Understand how pelvic floor activates with running for support of thorax and maintenance of continence.
4. Understand how to coordinate pelvic floor with other supporting muscles of thorax with running

What is the Pelvic Floor?
• Group of muscles at the base of the pelvis
• Works alongside the abdominal and spinal muscles
• Coordinates with the diaphragm to control intra-abdominal pressure

Bony Structures of Pelvic Girdle
• Innominates
• Lumbar spine
• Sacrum
• Coccyx
• Hip joints

Physiology of the pelvic floor
• Muscle fibers are intertwined and act as a functional unit
• At rest the pelvic floor has an active resting tone to maintain continence
• Pelvic floor muscles (PFM): are made up of 70% slow twitch, and 30% fast twitch
  • Slow twitch muscle fibers maintain base tone while fast twitch fibers are recruited for rapid contractions
  • Lee, D 2016, Padoa, A, 2016
Pelvic Floor Musculature (PFM)

- **Layer 1**: Bulbospongiosus, Ischiocavernosus, superficial transverse perineal
- **Layer 2**: Urethral sphincter, urethrovaginalis, deep transverse perineal
- **Layer 3**: Iliococcygeus, puborectalis (levator ani), coccygeus, and obturator internus

Pelvic Floor Superficial layers
- Share common attachments at perineal body

Pelvic Floor Levator ani group
- Share tendinous attachments with obturator internus via the arcus tendinosus of levator ani (ATLA)
- Attach at coccyx, ilium, ischium and pubis
- This structural support is important for the stability of the ilium, sacrum and coccyx in relationship to the pelvic floor
- Abdominal pressure is transmitted to the urethra via attachment of fascia that is laterally subvesiculair to ATLA and PFM, thus impacting continence

Role of Obturator Internus in PFM support
- Synergist: PFM, abdominal wall, and hips
- Increased activity with running
  - Synergistic activation of PFM may help to tense pelvic fascial layers
- With connection to levator ani muscle the obturator internus (OI) contracts to assist in lifting the PFM
- Plays important role in pelvic organ support
- Tendons of piriformis and obturator internus join to form a conjoint tendon before inserting on to the proximal femur and hip capsule
Diaphragm to psoas to obturator internus to levator ani fascial plane

- Fascial plane and muscle fiber interdigitation between diaphragm and iliopsoas into obturator internus and into levator ani musculature

Role of facial layers in continence

- Delancey Hammock theory: increased intra-abdominal pressure positively affects urethral closure pressure and contributes to continence
- Initial phase of increased intravaginal pressure during abdominal contraction is caused by pelvic floor muscle activation
- Abdominal pressure is transmitted to the urethra through lateral subvesicular attachment to ATLA and PFM
- Endopelvic fascial tissue structure stiffens during the reflex contraction of the PFM and forms a supportive layer against which the urethra is compressed.  
  - Leitner et al. 2017

Functions of the Pelvic Floor

- Supportive: helps to support organs and forms the bottom of the “core”
- Sphincteric: controls openings of urethra, rectum and vagina
- Sexual: orgasm, arousal and relaxation
- Stability: assists in stability of sacroiliac joint, pubic symphysis, lumbosacral, and hip joints
- Sump-pump: venous, lymphatic pump
  - Herman and Wallace PF1

Biomechanics of pelvic floor muscles

- Contraction
  - Closes vaginal, urethral and anal openings
  - Creates a lift of the perineum
  - Ischial tuberosities move together
  - Pubis and coccyx come toward each other
  - Voluntary contraction of PFM causes elevation of PFM and abdominal viscera

- Elongation
  - Opens vagina, urethral and anal openings
  - Perineum descends
  - Pelvis opens with widening of ischial tuberosities
  - Coccyx and pubis move away from each other
  - Lengthening of pelvic floor musculature eccentrically

Incidence of Stress Urinary Incontinence (SUI) in female athletes

- Many women limit themselves from running due to SUI
- Prevalence: 41% in female elite athletes
- Highest prevalence is found in sports involving high impact activities
- Ground reaction forces between 1.6 and 2.5 times bodyweight have been found in running at moderate speed
- Assumed that those forces are also transmitted to the pelvic floor
  - Leitner et al. 2017, Moser et al. 2017
Timing of pelvic floor and running

- In incontinent women, the delay between heel strike and contraction of the PFM is prolonged
- Continent women have greater upward displacement of PFM and viscera with elevation
- Increases of PFM activity with higher speed can be explained by rising ground reaction forces and associated higher force demands for the PFMs

Moser et al. 2017

PFM and Central Nervous System (CNS) role in trunk support

- Pelvic floor and transverse abdominus respond in a feedforward manner via CNS according to the reactive forces of trunk and increasing intra-abdominal pressure
- Gradual adaptation of PFM is an important factor in continence meaning as we have increased level of activity we have increased PFM and abdominal activation

Luginbuehl et al. 2016, Leitner et al. 2017

Gradual adaptation of PFM

- **There is no significant change in PFM response during different intensities in women with SUI**
- Gradual adaptation of PFM is an important factor in maintaining continence
- This gradual adaptation also evident with different running speeds (increased running speeds= increased PF adaptation)


PFM reflex activity with running

- Reflex activity suggests stretch-shortening cycle which consists of pre-activity, eccentric lengthening, and concentric contraction
- Eccentric lengthening is reactive and a stronger contraction can follow which allows for increased muscle strength in a shorter period of time
- Clinically, important to train not only PFM activation but also elongation for improved eccentric muscle control pending patient findings

Luginbuehl et al. 2016

Electromyography (EMG) with eccentric vs concentric muscle activation

- Muscles must be electrically active during elongation or stretch of the muscle
- Eccentric muscle actions produce less EMG activation vs concentric muscle contractions

Luginbuehl et al. 2016

Normal PFM patterns on EMG with vaginal sensor

- Voluntary concentric PFM contraction causes cranial displacement and backward rotation of the sensor
- Backward rotation interpreted as compression of the bladder against the PFM and vaginal wall
- Eccentric PFM contractions causes caudal displacement and forward rotation of the probe

Leitner et al. 2017
Assessment of PFM with vaginal sensor EMG prior to heel strike

- In preparation of heel strike, eccentric muscle activation cause caudal translation and forward rotation accompanied with increased muscle activity on EMG
- Pre-activity prior to heel strike prepares the tendon-muscle system for the absorption of impact forces
- **Eccentric phase is not triggered by heel strike but precedes it**
  - Leitner et al. 2017

Assessment of PFM with vaginal sensor EMG at heel strike

- Upon heel strike, voluntary concentric muscle contractions causes cranial translation and backward rotation showing lift of levator ani muscles and compression of urethra
- Heel strike terminated the caudal displacement of PFM
- Heel strike initiated a quick concentric contraction
- Maximum backward rotation occurs between 71-114 ms after heel strike
- No difference between continent and incontinent women with PFM displacement and rotation
  - Leitner et al. 2017

PFM activation on EMG with running

- **Static standing**: 29.6 %EMG
- **Prior to heel strike**: Eccentric lengthen occurs;
  - Running EMG pre-activity of 72 %EMG at 50 ms prior to heel strike during running at 8 km/hr
- **After heel strike**: concentric contraction occurs
  - Increased EMG activity to 124 %EMG within 214 ms
- **During running**: max PFM activation varied per person and speed
  - activity varied from 98 to 238%EMG and pre-activity from 72 to 136% EMG

PFM activity in women and SUI

- PFM can activate to level higher than MVC during impact activities.
- PFM can increase to 200%EMG in incontinent women during running.
- **During impact activities, incontinent women had higher PFM activity than continent women**
  - Leitner et al. 2017, Moser et al. 2017

EMG with changes in running speed

- Values higher with faster running speeds vs slower running speeds.
- Higher PFM activity with faster running due to reflexive and reactive force generation with running
- Hypothesize during 11 km/hr speed, a fast monosynaptic reflex follows the impact of initial contact
  - Lugrinbuehl et al 2017

Timing of abdominal wall and PFM muscles activation

- During impact activities, PFM contract before other trunk muscles in continent women
- In incontinent women, PFM contract after other trunk muscles
- Time from onset of PFM activity to the onset of intra-abdominal pressure, urethral, and posterior vaginal wall pressure increases contributes to continence.
- PFM activation and increased urethral pressure before the increase in intra-abdominal pressure assist in maintaining continence
  - Leitner et al. 2017, Dias et al. 2017
Treatment

**Treatment Strategies for PFM with Running**

- Assess PFM on EMG while running for PFM activation prior to heel strike and with heel strike
  - Eccentric lengthening is occurring prior to heel strike
- Assess trunk muscle activation strategies with running, keeping in mind the importance of timing activation of abdominal wall and PFM
  - Feed forward system
- Look at ability to activate PFM with different forces to adapt to different levels of abdominal pressure and GRF
  - Look at running speed!

**PFM assessment**

- To maximize PFM activation for lift and closure of urethra, the PFM must also be able to eccentrically elongate prior to heel strike
- Important to assess ability to both concentrically and eccentrically activate PFM for best trunk control with running
- Can assess with EMG or digital vaginal assessment

**PFM activation in women with SUI**

- Incontinent women have higher PFM activity than continent women during impact activities.
- Suggests that although women with incontinence may have reduced muscle mass and maximal ability, the activity of their PFM is greater during postural perturbations
  - Leitner et al. 2017, Moser et al. 2017

**Strengthening PFM**

- PFM activation with cues to “Bring tailbone to pubic bone” or “Visualize stopping passing gas and urine”
- PFM activation should occur in conjunction with transverse abdominus (TrA) for maximum trunk control
- Train PFM and TrA with functional activities for muscle strength and motor control

**High PFM tone considerations with SUI**

- Women with SUI have increased PFM activity on EMG.
- PFM hypertonicity may be contributing to SUI
- This subset will not respond positively to PFM strengthening protocols due to poor ability to elongate and activate PFM
  - Relaxation or “down training” of PFM using biofeedback or tactile cues
  - Contract/relax to fatigue
  - Diaphragmatic breathing
  - Trigger point release/soft tissue mobilization
  - Postural and body mechanics education
- Good referral to PFM PT for further assessment for appropriate treatment
Using Running as Treatment

• Running should be considered for SUI treatment options to increase reflex activity of PFM
• Training protocols should include involuntary reflexive muscle activity
  • Quick changes in direction
  • Increasing and decreasing running speeds and incline
  • Jumping and hopping activities
• Remember to look at the entire system!
  • Moser et al 2017

References

• Lee D. The Pelvic Girdle: An Integration of Clinical Expertise and Research. Churchill Livingstone. 2011
• Padoa A, Rosenbaum T. The overactive pelvic floor. 2016.