CHAPTER 4

Testing the Muscles of the Trunk and Pelvic Floor

Trunk Extension

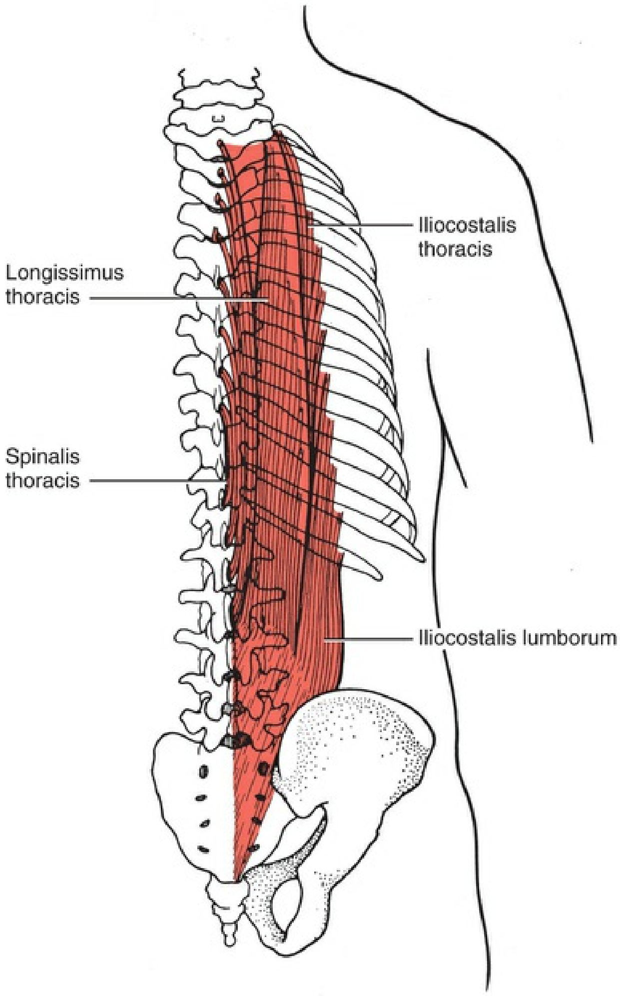

FIGURE 4.1

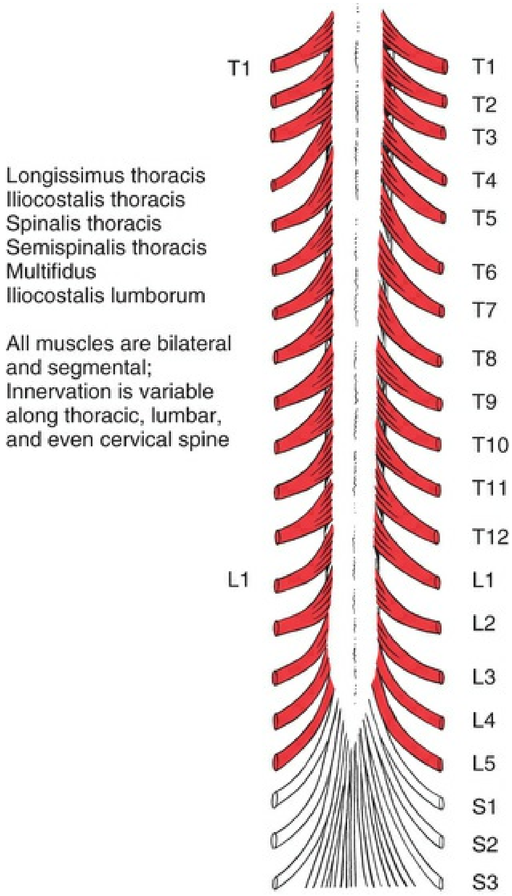

FIGURE 4.2

Range of Motion

Thoracic spine: 0°–10°
Lumbar spine: 0°–25°

Table 4.1
TRUNK EXTENSION

I.D.	Muscle	Origin	Insertion	Function
89	Iliocostalis thoracis	Ribs 12 up to 7 (angles)	Ribs 6 up to 1 (angles) C7 vertebra (transverse processes)	Extension of the spine Lateral bending of spine to same side (muscles on one side) Depression of ribs
90	Iliocostalis lumborum	Tendon of erector spinae (anterior surface) Thoracolumbar fascia Sacrum (posterior surface)	Ribs 6–12 (angles)	Extension of spine Lateral bending of spine (muscles on one side) Depression of ribs (lumborum) Elevation of pelvis
91	Longissimus thoracis	Tendon of erector spinae Thoracolumbar fascia L1-L5 vertebrae (transverse processes)	T1-T12 vertebrae (transverse processes) Ribs 2–12 (between angles and tubercles)	Extension of the spine Lateral bending of spine to same side (muscles on one side) Depression of ribs
92	Spinalis thoracis (often indistinct)	Common tendon of erector spinae T11-L2 vertebrae (spinous processes)	T1-T4 vertebrae (or to T8, spinous processes) Blends with semispinalis thoracis	Extension of spine
93	Semispinalis thoracis	T6-T10 vertebrae (transverse processes)	C6-T4 vertebrae (spinous processes)	Extension of thoracic spine
94	Multifidi	Sacrum (posterior) Erector spinae (aponeurosis) Ilium (posterior superior iliac spine [PSIS]) and crest Sacroiliac ligaments L1-L5 vertebrae (mamillary processes) T1-T12 vertebrae (transverse processes) C4-C7 vertebrae (articular processes)	Spinous processes of higher vertebra (may span 2–4 vertebrae before inserting)	Extension of spine Lateral bending of spine (muscle on one side) Rotation to opposite side
95, 96	Rotatores thoracis and lumborum (11 pairs)	Thoracic and lumbar vertebrae (transverse processes; variable in lumbar area)	Next highest vertebra (lower border of lamina)	Extension of thoracic spine Rotation to opposite side
97, 98	Interspinales thoracis and lumborum	Thoracis: (3 pairs) between spinous processes of	See origin	Extension of spine

		contiguous vertebrae (T1-T2; T2-T3; T11-T12) Lumborum: (4 pairs) lie between the 5 lumbar vertebrae; run between spinous processes		
99	Intertransversarii thoracis and lumborum	Thoracis: (3 pairs) between transverse processes of contiguous vertebrae T10-T12 and L1 Lumborum: medial muscles; accessory process of superior vertebra to mamillary process of vertebra below Lateral muscles: fill space between transverse processes of adjacent vertebrae	See origin	Extension of spine (muscles on both sides) Lateral bending to same side (muscles on one side) Rotation to opposite side
100	Quadratus lumborum	Ilium (crest and inner lip) Iliolumbar ligament	12th rib (lower border) L1-L4 vertebrae (transverse processes) T12 vertebra (body)	Elevation of pelvis (weak in contrast to lateral abdominals) Extension of lumbar spine (muscles on both sides) Inspiration (via stabilization of lower attachments of diaphragm) Fixation of lower portions of diaphragm for prolonged vocalization, which needs sustained expiration. Lateral bending of lumbar spine to same side (pelvis fixed) Fixation and depression of 12th rib
Other				
182	Gluteus maximus (provides stable base for trunk extension by stabilizing pelvis)			

The importance of the spinal extensors' muscle strength and endurance cannot be understated as they are implicated in back pain, posture, gait, and balance. For example, in older women with severely flexed posture (>8 cm from occiput to the wall), spinal extensors and abdominal muscles were found to be weaker than in those with mildly flexed posture.[1] Exaggerated posture such as extreme lumbar lordosis and pelvic tilt produce greater muscle activity than more optimal postures, and this has implications for physical therapists.[2] Muscle function in the neutral zone is important for stabilization of the lumbar spine.[3,4] Stabilization occurs through global and local stabilizers. The global stabilizers include the rectus abdominis and external oblique muscles. These muscles generate a large amount of muscle torque across multiple segments and thus control movement. The local stabilizers are the deeper muscles, having their origin or insertion directly or indirectly on the lumbar vertebrae. The transversus abdominis (TA) and lumbar multifidus (LM) are examples of local stabilizers. This system of global and local stabilizers is what provides lumbar stabilization.[5,6] The trunk flexors and extensors form the core, discussed later in this chapter.

The trunk extensor muscles are tonic or endurance-type muscles, whereas the trunk flexors are phasic or shorter acting. Therefore the maximum force generated per unit of muscle mass should be expected to be different (less for the extensors). Trunk extensor endurance has a role in upright posture and back pain, and therefore it may be informative to test the patient's hold time. Trunk extensors also control trunk flexion eccentrically.

Although there is no “gold standard” for the testing of spinal and abdominal muscles, this chapter includes methods from the best evidence as well as time-honored traditional methods.

Lumbar Spine

Grade 5 and Grade 4

Position of Patient:

Prone with fingertips lightly touching the side of the head and shoulders in external rotation. The weight of the head and arms essentially substitutes for manual resistance by therapist.

Instructions to Therapist:

Stand at side of patient to stabilize the lower extremities just above the ankles (Fig. 4.3). Ask patient to raise the head, shoulders, and chest off the table. Observe quality of motion and ability to hold the test position.

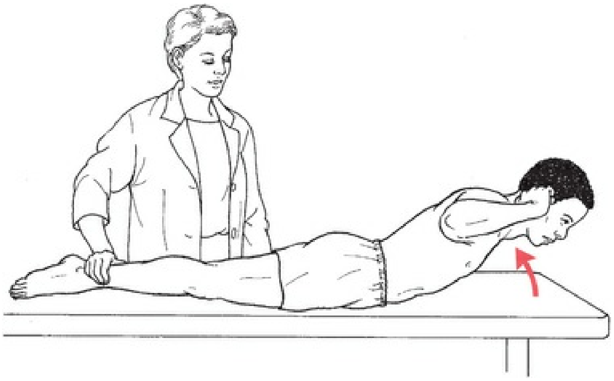

FIGURE 4.3

Alternate Instructions to Therapist:

If the patient has hip extension weakness, stabilize the lower extremities by leaning firmly over the patient's body, placing both arms across the pelvis. Note it is very difficult to stabilize the pelvis adequately in the presence of significant hip weakness (Fig. 4.4).

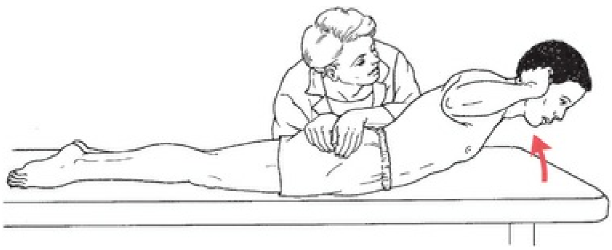

FIGURE 4.4

Test:

Patient extends the lumbar spine until the entire trunk is raised from the table (clears umbilicus).

Instructions to Patient:

“Raise your head, shoulders, and chest off the table. Come up as high as you can.”

Grading

Grade 5 and Grade 4:

The therapist distinguishes between Grade 5 and Grade 4 muscles by observing the response (see Figs. 4.3 and 4.4). The Grade 5 muscle holds the test position like a lock; the Grade 4 muscle yields slightly because of an elastic quality at the end point. The patient with Grade 5 back extensor muscles can quickly come to the end position and hold that position without evidence of significant effort. The patient with Grade 4 back extensors can come to the end position but may waver or display some signs of effort.

Thoracic Spine

Grade 5 and Grade 4

Position of Patient:

Prone with head and upper trunk extending off the table from about the nipple line (Fig. 4.5). Hands should be lightly touching the side of the head, with shoulders and elbows retracted (back).

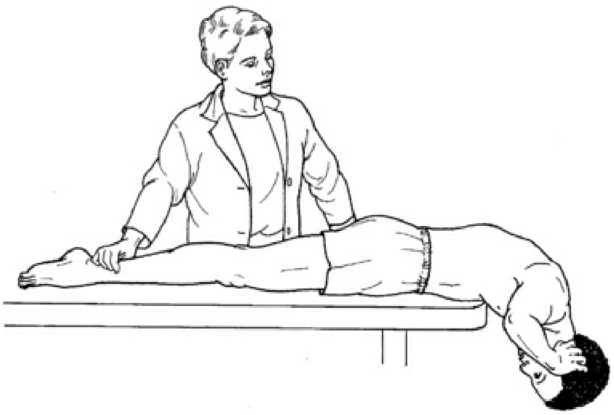

FIGURE 4.5

Instructions to Therapist:

Stand at side of patient to stabilize the lower limbs at the ankle. Ask patient to raise the head, shoulders, and chest to table level. (Note that this position does not require the same degree of stabilization as the lumbar extension tests.)

Test:

Patient extends thoracic spine to the horizontal. This will be a small movement, and care should be made not to extend farther than horizontal because further movement will cause lumbar extension.

Instructions to Patient:

"Raise your head, shoulders, and chest to table level."

Grading

Grade 5:

Patient raises the upper trunk quickly from its forward flexed position to the horizontal with ease and no sign of exertion (Fig. 4.6).

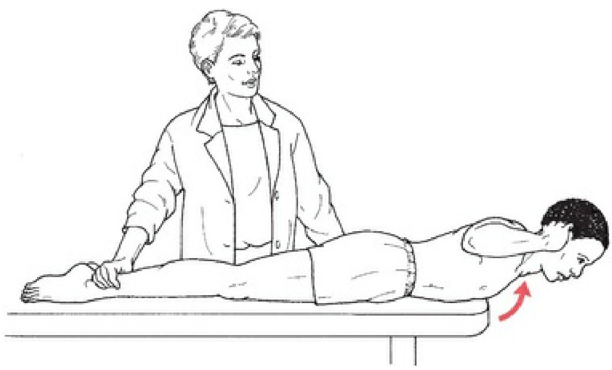

FIGURE 4.6

Grade 4:

Patient raises the trunk to the horizontal level but does so with obvious effort.

Grade 3

Note: Grades 3, 2, 1, and 0 tests involve the lumbar and thoracic spine.

Position of Patient:

Prone with arms at sides.

Instructions to Therapist:

Stand at side of table. Stabilize lower extremities just above the ankles.

Test:

Patient extends spine, raising body from the table so that the umbilicus clears the table (Fig. 4.7).

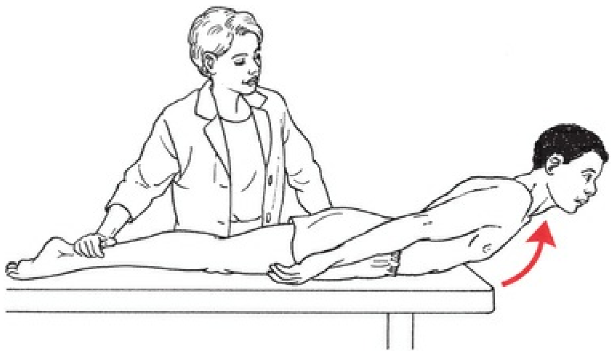

FIGURE 4.7

Instructions to Patient:

"Raise your head, arms, and chest from the table as high as you can."

Grading

Grade 3:

Patient completes the range of motion.

Grade 2, Grade 1, and Grade 0

These tests are identical to the Grade 3 test except that the therapist must palpate the lumbar and thoracic spine extensor muscle masses adjacent to both sides of the spine. The individual muscles cannot be isolated (Figs. 4.8 and 4.9).

FIGURE 4.8

FIGURE 4.9

Grading

Grade 2:

Patient completes partial range of motion.

Grade 1:

Contractile activity is detectable but no movement.

Grade 0:

No discernable contractile activity.

Helpful Hints

- When the spinal extensors are strong and the hip extensors are weak, the patient can hyperextend the low back (increased lordosis) but will be unable to raise the trunk without very strong stabilization of the pelvis by the therapist.
- If the neck extensors are weak, the therapist may need to support the head as the patient raises the trunk.
- When the spinal extensors are weak and the hip extensors are strong, the patient will be unable to raise the upper trunk from the table. Instead, the pelvis will tilt posteriorly while the lumbar spine moves into flexion (low back flattens).
- If the hip extensor muscles are Grade 4 or better, it may be helpful to use belts to anchor hips to the table, especially if the patient is much larger or stronger than the testing therapist.
- If the patient is unable to provide stabilization through the weight of the legs and pelvis (such as in paraplegia or amputee), the test should be done on a mat table. Position the subject with both legs and pelvis off the mat. This allows the pelvis and limbs to contribute to stabilization, and the therapist holding the lower trunk has a chance to provide the necessary support. (If a mat table is not available, an assistant will be required, and the lower body may rest on a chair.)

Sørensen Lumbar Spine Extension Test

The Biering-Sørensen test or Sørensen test is a measure of isometric endurance capacity of the back extensors and perhaps hip extensor muscles.[7,8] The modified Sørensen test is a similar test with patient arms at the side of the trunk, rather than across the chest, as in the original Biering-Sørensen test.

Position of Patient:

Prone with the trunk flexed off the end of the table at a level between the anterior superior iliac spine (ASIS) and umbilicus. Until test begins, patient may stretch arms over a chair (in front of table) to provide support for the trunk (not shown).

Instructions to Therapist:

Lean over patient to firmly stabilize the lower limbs and pelvis at the ankles. Ask patient to fold arms across the chest, then raise head, chest, and trunk so the trunk is straight. Use a stopwatch to time the effort, activating it at the "begin" command and stopping it when the patient shows obvious signs of fatigue and begins to falter.[9]

Test:

Patient lifts the trunk to the horizontal and maintains the test position as long as possible (Fig. 4.10).

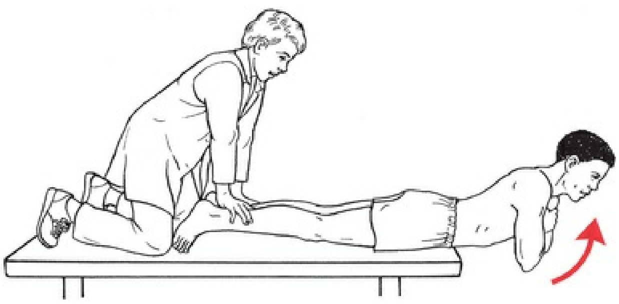

FIGURE 4.10

Instructions to Patient:

"When I say 'begin,' lift your head, chest, and trunk from the table and hold the position as long as you can. I will be timing you."

Helpful Hints

- The Sørensen test elicits no greater than 40%–52% of the maximal voluntary contractile force.[8]
- Back extensor strength declines approximately 40%–50% from the 3rd to 8th decades of life, markedly reducing endurance time (Table 4.2).[10-12]

Table 4.2

AGE-BASED NORMS FOR MODIFIED SØRENSEN TEST

Age	Mean Hold Time in Seconds (SD)* Males	Mean Hold Time in Seconds (SD) Females
19-29	140[12]	130[15]
30-39	130[12]	120
35-39	97 (43)[15]	93 (55)[15]
40-44	101 (57)[15]	80 (55)[15]
40-49	120[12]	90[15]
45-49	99 (58)[15]	102 (64)[15]
50-54	89 (55)[15]	69 (60)[15]
50-59	90[12]	75[12]
60+	80[12]	90[12]

*Numbers in parentheses refer to standard deviation (SD). The standard deviation is only available for some age groups.

[12]Data from 561 healthy, nonsmoking subjects in Nigeria without low back pain.

[15]Data from 508 subjects with and without back pain that comprised equal groups of blue- and white-collar male and female subjects.

- The Sørensen test has been validated as a differential diagnostic test for low back pain.[7,13]
- With a cutoff score of 28 s for men and 29 s for women, the Sørensen test had a sensitivity of 92.3% and specificity of 76.0% to predict low back pain in men and 84.3% sensitivity and

84.6% specificity for women.[14]

Suggested Exercises for Lumbar Spine[16]

Isolation of lumbar extensors requires adequate restraint of the pelvis to limit involvement of the hip extensors.

- Roman Chair
- Deadlifts
- Squats
- Extension-based resistance machines

Elevation of the Pelvis

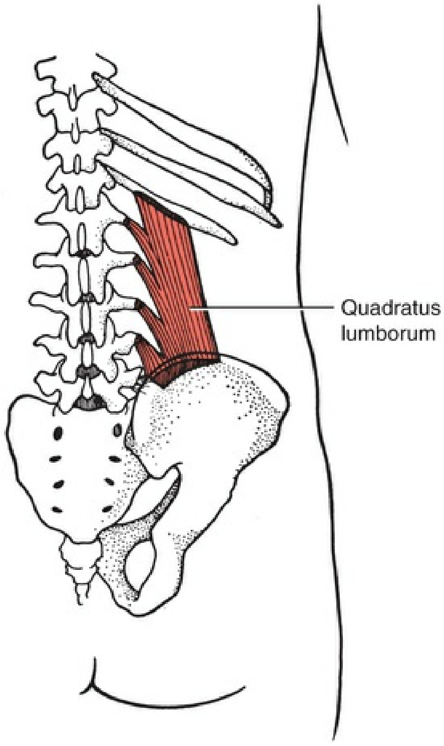

FIGURE 4.11

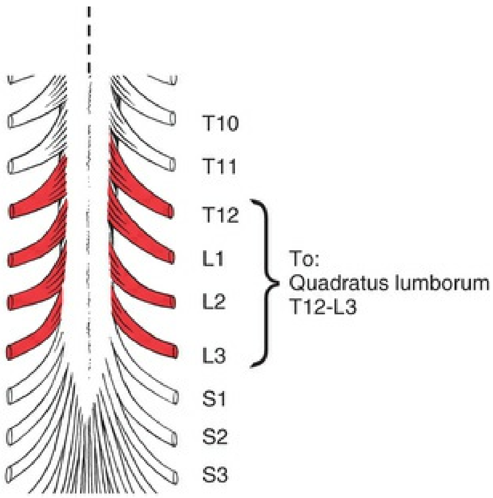

FIGURE 4.12

Range of Motion

Approximates pelvis to lower ribs; range not precise.

Table 4.3

ELEVATION OF THE PELVIS

I.D.	Muscle	Origin	Insertion	Function
110	**Obliquus externus abdominis**	Ribs 5–12 (interdigitating on external and inferior surfaces)	Iliac crest (outer border) Aponeurosis from 9th costal cartilage to ASIS; both sides meet at midline to form linea alba Pubic symphysis (upper border)	Flexion of trunk (bilateral muscles) Tilts pelvis posteriorly Elevates pelvis (unilateral) Rotation of trunk to opposite side (unilateral) Lateral bending of trunk (unilateral) Support and compression of abdominal viscera, counteracting effect of gravity on abdominal contents Assists defecation, micturition, emesis, and parturition (i.e., expulsion of contents of abdominal viscera and air from lungs) Important accessory muscle of forced expiration (during expiration it forces the viscera upward to elevate the diaphragm)
111	**Obliquus internus abdominis**	Iliac crest (anterior 2/3 of intermediate line) Thoracolumbar fascia Inguinal ligament (lateral 2/3 of upper aspect)	Ribs 9–12 (inferior border and cartilages by digitations that appear continuous with internal intercostals) Ribs 7–9 (cartilages) Aponeurosis to linea alba	Flexion of spine (bilateral) Lateral bending of spine (unilateral) Rotation of trunk to same side (unilateral) Increases abdominal pressure to assist in defecation and other expulsive actions Forces viscera upward during expiration to elevate diaphragm Elevation of pelvis
100	Quadratus lumborum	Ilium (crest and inner lip) Iliolumbar ligament	Rib 12 (lower border) L1-L4 vertebrae (transverse processes, apex) T12 vertebra (body; occasionally)	Elevation of pelvis (weak in contrast to lateral abdominals) Extension of lumbar spine (muscles on both sides) Inspiration (via stabilization of lower attachments of diaphragm) Fixation of lower portions of diaphragm for prolonged vocalization which needs sustained expiration. Lateral bending of lumbar spine to same side (pelvis fixed) Fixation and depression of 12th rib
Others				
130	Latissimus dorsi (if arms are fixed)			
90	Iliocostalis lumborum			

ASIS, Anterior superior iliac spine.

Elevation of the pelvis is a critical component of gait because it allows the swing leg to clear the floor. The lateral abdominals, in conjunction with the quadratus, produce very strong pelvic elevation, and the therapist should not be able to break a Grade 5 muscle. The hip hike test described later was originally believed to isolate the quadratus lumborum, but a later study revealed the dominance of the abdominals. Even though hip hiking incorporates both the abdominals and quadratus,[17] it is still the best differentiation between quadratus and the abdominals that we have.

Grade 5 and Grade 4

Position of Patient:

Supine or prone. The patient grasps edges of the table to provide stabilization during resistance (not illustrated).

Instructions to Therapist:

Stand at foot of table, facing patient. Ask patient to hike pelvis. If sufficient range is present, grasp test limb with both hands, using a lumbrical grip just above the ankle, and pull caudally with a smooth, even pull (Fig. 4.13) to provide resistance. Resistance is given as in traction. The Grades 5 and 4 muscles tolerate a very large amount of resistance.

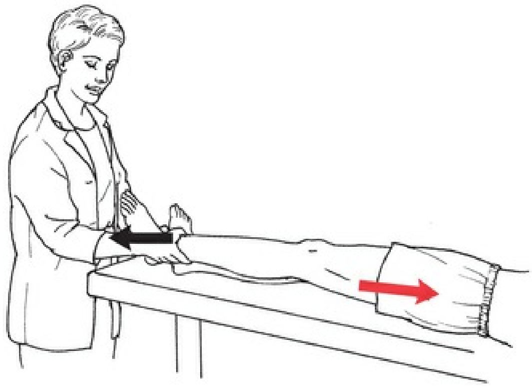

FIGURE 4.13

Test:

Patient hikes the pelvis on one side, thereby approximating the pelvic rim to the inferior margin of the rib cage.

Instructions to Patient:

"Hike your pelvis to bring it up to your ribs. Hold it. Don't let me pull your leg down."

Grading

Grade 5:

Patient holds test position and limb does not move with maximal resistance.

Grade 4:

Patient holds test position against very strong resistance. Testing this movement requires more than a bit of clinical judgment.

Grade 3 and Grade 2

Position of Patient:

Supine or prone. Hip in extension; lumbar spine neutral or extended.

Instructions to Therapist:

Stand at foot of table, facing patient. Use one hand to support the leg just above the ankle; keep the other hand under the knee so the limb is slightly off the table to decrease friction (Fig. 4.14).

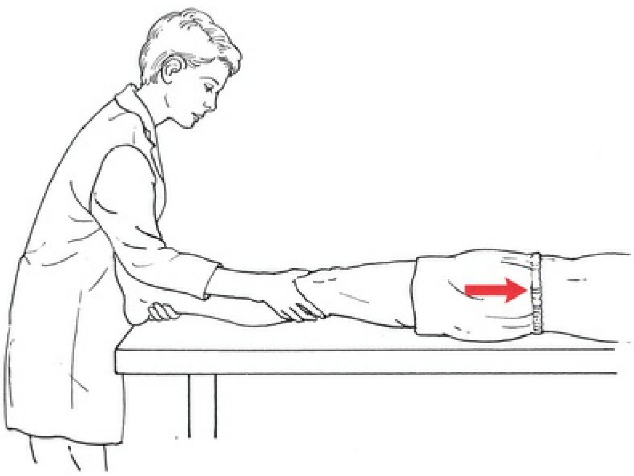

FIGURE 4.14

Test:

Patient hikes the pelvis on the test side to bring the rim of the pelvis closer to the inferior ribs.

Instructions to Patient:

"Bring your pelvis up to your ribs."

Grading

Grade 3:

Patient completes available range of motion.

Grade 2:

Patient completes partial range of motion.

Grade 1 and Grade 0

These grades should be avoided to ensure clinical accuracy. The quadratus lumborum lies deep to the paraspinal muscle mass and can rarely be palpated. In people who have extensive truncal atrophy, paraspinal muscle activity may be palpated, and possibly, but not necessarily convincingly, the quadratus lumborum can be palpated.

Substitution

The patient may attempt to substitute with trunk lateral flexion, primarily using the abdominal muscles. The spinal extensors may be used without the quadratus lumborum. In neither case can manual testing detect an inactive quadratus lumborum.

Helpful Hint

It should be noted that the quadratus lumborum may have functions other than hip hiking, such as maintaining upright posture, although these functions have been less well studied. Quadratus lumborum strength has also been linked to low back pain and thus may deserve closer analysis.[18]

Trunk Flexion

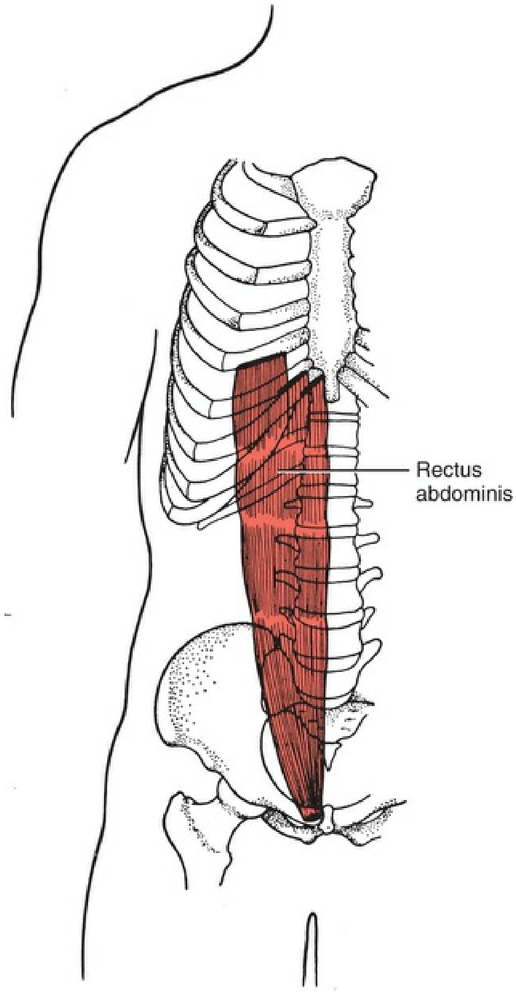

FIGURE 4.15

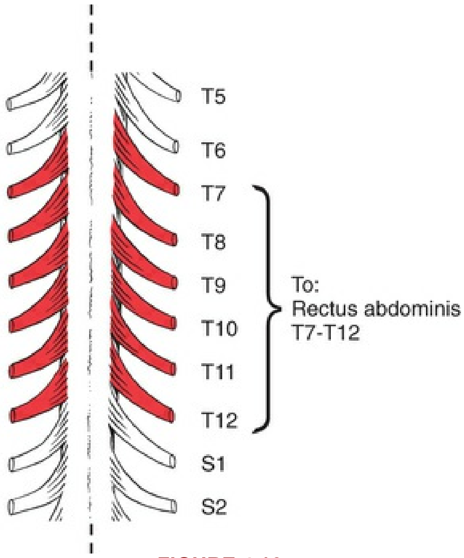

FIGURE 4.16

Range of Motion

0°–80°

Table 4.4
TRUNK FLEXION

I.D.	Muscle	Origin	Insertion	Function
113	**Rectus abdominis** (paired muscle)	Pubis Lateral fibers (tubercle on crest and pecten pubis) Medial fibers (ligamentous covering of symphysis attaches to contralateral muscle)	Ribs 5–7 (costal cartilages) Sternum (xiphoid ligaments)	Flexion of the spine (draws symphysis pubis and sternum toward each other) Posterior tilt of pelvis
110	**Obliquus externus abdominis**	Ribs 5–12 (interdigitating on external and inferior surfaces)	Iliac crest (outer border) Aponeurosis from 9th costal cartilage to ASIS; both sides meet at midline to form linea alba	Flexion of the trunk Tilts pelvis posteriorly Elevates pelvis (unilateral) Rotation of trunk to opposite side (unilateral) Accessory muscle of forced expiration
111	**Obliquus internus abdominis**	Iliac crest (anterior ⅔ of intermediate line) Thoracolumbar fascia Inguinal ligament (lateral ⅔ of upper aspect)	Ribs 9–12 (inferior border and cartilages by digitations that appear continuous with internal intercostals) Ribs 7–9 (cartilages) Aponeurosis to linea alba	Flexion of spine Lateral bending of the spine (unilateral) Rotation of trunk to same side (unilateral) Elevation of pelvis
Others				
174	Psoas major			
175	Psoas minor			

ASIS, Anterior superior iliac spine.

Trunk flexion has multiple elements that include cervical, thoracic, and lumbar motion. Measurement is difficult at best and may be done in a variety of ways with considerable variability in results. The neck flexors should be eliminated as much as possible by asking the patient to maintain a neutral neck position with the chin pointed to the ceiling to avoid neck flexion. Legs should be straight to avoid hip flexor activation.[19]

Grade 5

Position of Patient:

Supine, with legs straight and fingertips lightly touching the back of the head (Fig. 4.17).

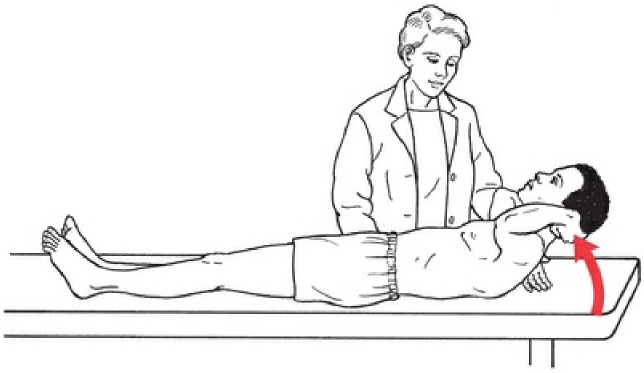

FIGURE 4.17

Instructions to Therapist:

Stand at side of table at level of patient's chest to ascertain whether scapulae clear table during test (Fig. 4.18). Ask patient to lift head, shoulders, and back off table, keeping the chin pointed to the ceiling. Observe motion for quality and effort. For a patient with no other muscle weakness, the therapist does not need to touch the patient. However, if the patient has weak hip flexors, the therapist should stabilize the pelvis by leaning across the patient on the forearms (see Fig. 4.18).

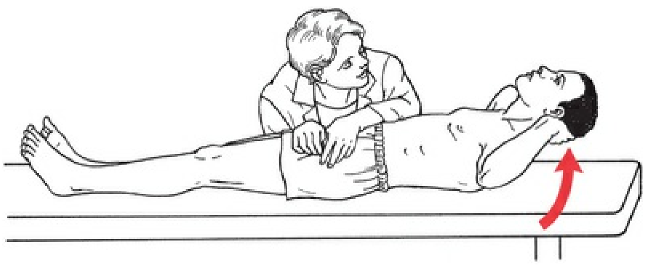

FIGURE 4.18

Test:

Patient flexes trunk through range of motion, lifting the trunk until scapulae clear table. The neck should not flex.

Instructions to Patient:

"Keep your chin pointed toward the ceiling and lift your head, shoulders, and back off the table."

Grading

Grade 5:

Patient raises trunk until inferior angles of scapulae are off the table. (Weight of the arms serves as resistance.)

Grade 4

Position of Patient:

Supine with arms crossed over chest (Fig. 4.19).

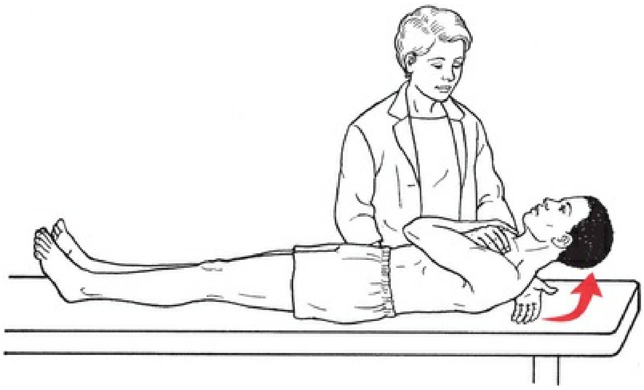

FIGURE 4.19

Test:

Other than the patient's arm position, all other aspects of the test are the same as for Grade 5.

Grading

Grade 4:

Patient raises trunk until scapulae are off the table. Resistance of arms is reduced in the cross-chest position.

Grade 3

Position of Patient:

Supine with arms outstretched in full extension above plane of body (Fig. 4.20).

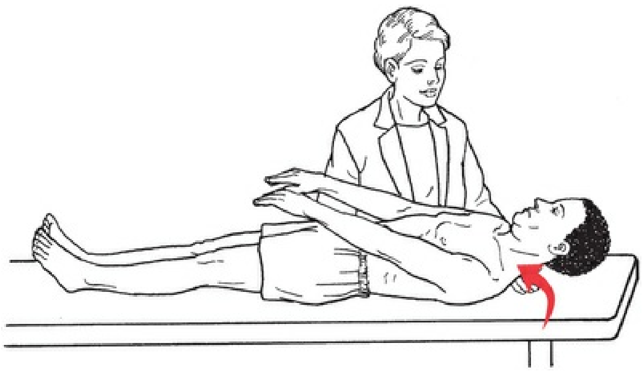

FIGURE 4.20

Test:

Except for the patient's arm position, all other aspects of the test are the same as for Grade 5. Patient lifts trunk until inferior angles of scapulae are off the table. Position of the outstretched arms "neutralizes" resistance by bringing the weight of the arms closer to the center of gravity.

Instructions to Patient:

"Keep your chin pointed to the ceiling as you raise your head, shoulders, and arms off the table."

Grading

Grade 3:

Patient lifts trunk until inferior angles of scapulae are off the table.

Grade 2, Grade 1, and Grade 0

Testing trunk flexion is rather clear-cut for Grades 5, 4, and 3. When testing Grade 2 and below, the results may be ambiguous, but observation and palpation are critical for defendable results. To determine Grades 2 to 0, the patient will be asked, in sequence, to raise the head, do an assisted forward lean, and cough.

Position of Patient:

Supine with arms at sides. Knees flexed.

Instructions to Therapist:

Stand at side of table. Place the hand used for palpation at the midline of the thorax over the linea alba, and use the four fingers of both hands to palpate the rectus abdominis (Fig. 4.21).

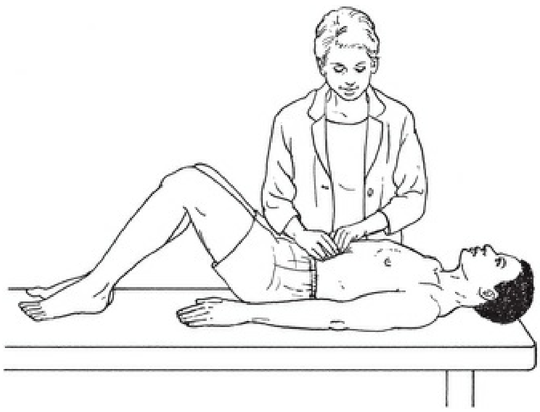

FIGURE 4.21

Note: The therapist tests for Grades 2, 1, and 0 in a variety of ways to make certain that muscle contractile activity that may be present is not missed.

Grading

Sequence 1:

Head raise (Fig. 4.22): Ask the patient to lift the head from the table. If the scapulae do not clear the table, the Grade is 2. If the patient cannot lift the head, proceed to Sequence 2.

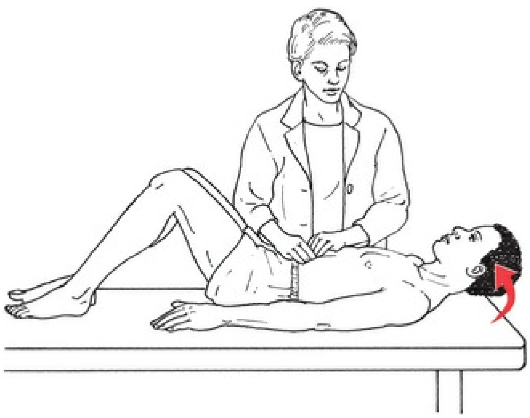

FIGURE 4.22

Sequence 2:

Assisted forward lean (Fig. 4.23): The therapist cradles the upper trunk and head off the table and asks the patient to lean forward. If there is depression of the rib cage, the grade is 2. If there is no depression of the rib cage but visible or palpable contraction occurs, the grade assigned should be 1. If there is no activity, the grade is 0; proceed to Sequence 3.

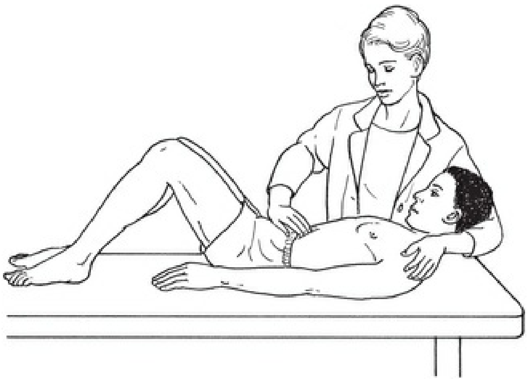

FIGURE 4.23

Sequence 3:

Cough (Fig. 4.24): Ask the patient to cough. If the patient can cough to any degree and depression of the rib cage occurs, the grade is 2. (If the patient coughs, regardless of its effectiveness, the abdominal muscles are automatically brought into play.) If the patient cannot cough but there is palpable rectus abdominis activity, the grade is 1. Lack of any discernable activity is Grade 0.

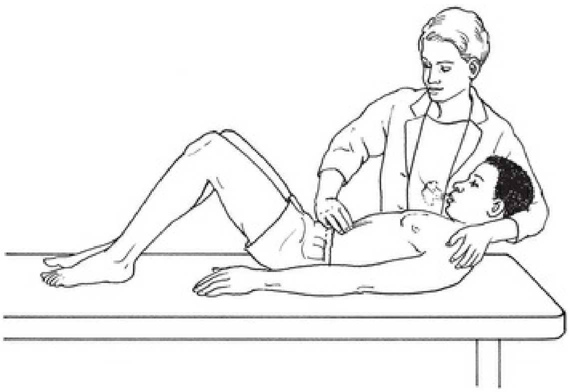

FIGURE 4.24

Helpful Hints

- In all tests, observe any deviations of the umbilicus. If there is a difference in the segments of the rectus abdominis in response to muscle testing, the umbilicus will deviate toward the stronger part (i.e., cranially if the upper parts are stronger, caudally if the lower parts are stronger, and laterally if one or more segments of *one* rectus is paralyzed).
- If the extensor muscles of the lumbar spine are weak, contraction of the abdominal muscles can cause posterior tilt of the pelvis. If this situation exists, tension of the hip flexor muscles would be useful to stabilize the pelvis; therefore the therapist should position the patient in hip and knee flexion.
- The thoracic flexion muscle test should be done absolutely correctly—that is, with the neck in neutral to avoid undue strain on the neck and in the presence of known or suspected

osteoporosis. Care should be taken in the presence of osteoporosis because repeated trunk flexion can be related to increased risk of compression fractures of the spine. To avoid thoracic flexion, instruct the patient to keep the chin pointed to the ceiling and the elbows flat.

- To avoid cervical strain, have the patient avoid clasping the head with the hands. The hands should not carry any of the head's weight.
- Abdominal-strengthening exercises are performed with spine flexion and without hip flexion to reduce the role of hip flexors and undue disc compression.[19]
- Leg support during a pelvic tilt and fixed feet during spine and hip flexion exercises may decrease the intensity of rectus abdominis activity. Having the feet on the floor or fixed activates the hip flexors.[19]
- In summary, to ensure the patient's spine safety, remember these important guidelines.[19]
    a. Avoid active hip flexion or fixed feet.
    b. Do not allow the patient to pull the head up with the hands behind the head.

Trunk Rotation

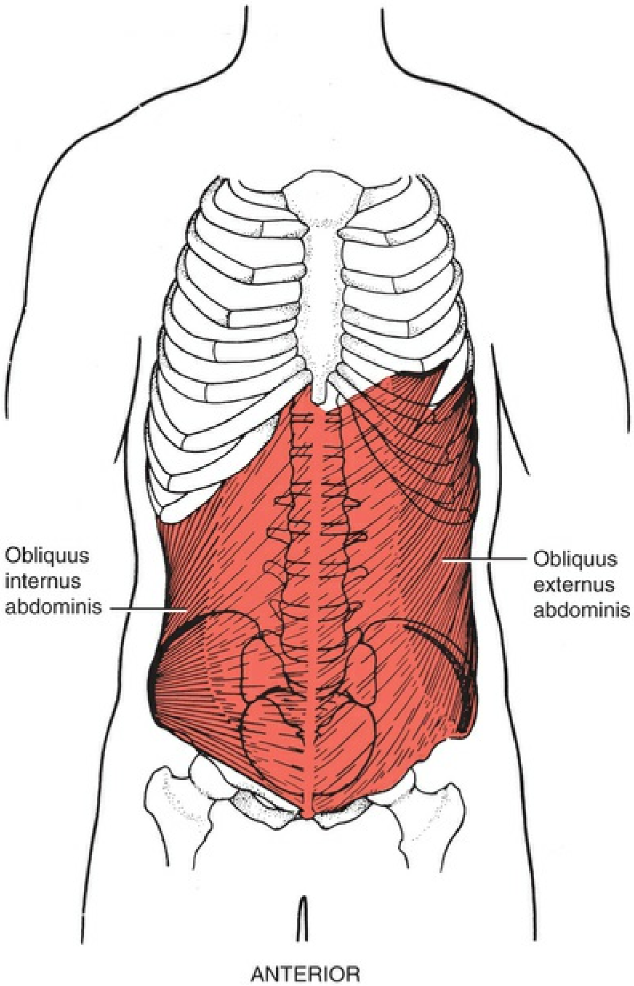

FIGURE 4.25

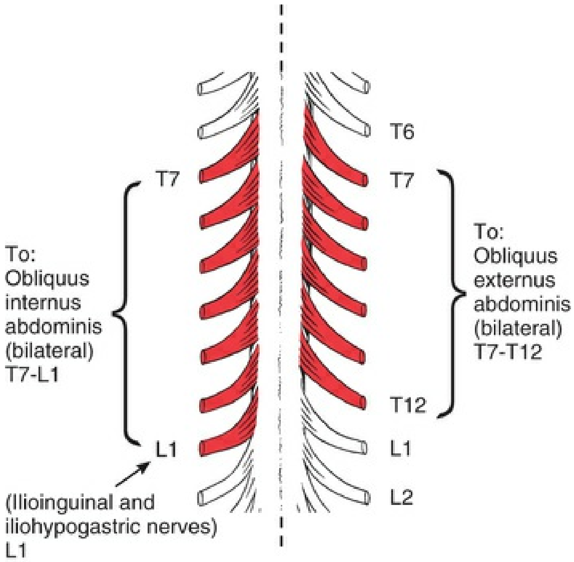

FIGURE 4.26

Range of Motion

0°–45°

Table 4.5
TRUNK ROTATION

I.D.	Muscle	Origin	Insertion	Function
110	**Obliquus externus abdominis**	Ribs 5–12 (interdigitating on external and inferior surfaces)	Iliac crest (outer border) Aponeurosis from 9th costal cartilage to ASIS; both sides meet at midline to form linea alba Pubic symphysis (upper border)	Flexion of trunk (bilateral muscles) Tilts pelvis posteriorly Elevates pelvis (unilateral) Rotation of trunk to opposite side (unilateral) Lateral bending of trunk (unilateral)
111	**Obliquus internus abdominis**	Iliac crest (anterior ⅔ of intermediate line) Thoracolumbar fascia Inguinal ligament (lateral ⅔ of upper aspect)	Ribs 9–12 (inferior border and cartilages by digitations that appear continuous with internal intercostals) Ribs 7–9 (cartilages) Aponeurosis to linea alba	Flexion of spine (bilateral) Lateral bending of spine (unilateral) Rotation of trunk to same side (unilateral) Elevation of pelvis
Other				
	Deep back muscles (1 side)			

NOTE: Use caution with trunk rotation in patients with known or suspected osteoporosis.

ASIS, Anterior superior iliac spine.

Trunk rotation is a combined and essential movement of most functional activities. Although the obliques are the primary movers, trunk rotation also involves the small oblique extensors and flexors.

Grade 5

Position of Patient:

Supine with fingertips to the side of the head.

Instructions to Therapist:

Stand at the patient's waist level. Ask the patient to lift head and shoulders, moving elbow to opposite hip. Repeat for other side. Observe for adequate range, quality of movement and effort.

Test:

With chin pointed to the ceiling, the patient flexes trunk and rotates to one side. This movement is then repeated on the opposite side so that the muscles on both sides can be examined.

Right elbow to left knee tests the right external oblique and the left internal oblique. Left elbow to right knee tests the left external oblique and the right internal oblique (Fig. 4.27). When the patient rotates to one side, the internal oblique muscle is palpated on the side toward the turn; the external oblique muscle is palpated on the side away from the direction of turning (Fig. 4.28).

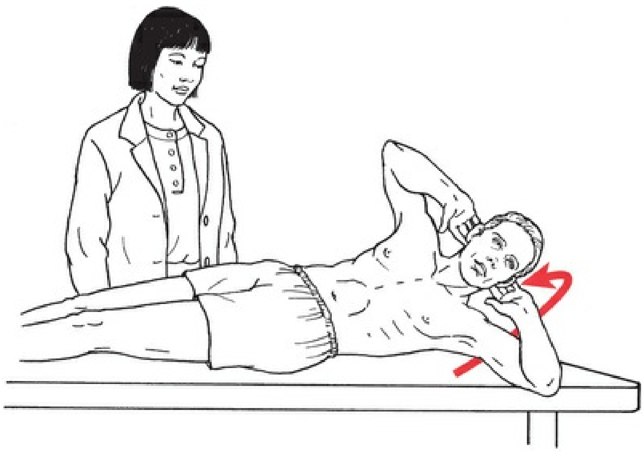

FIGURE 4.27

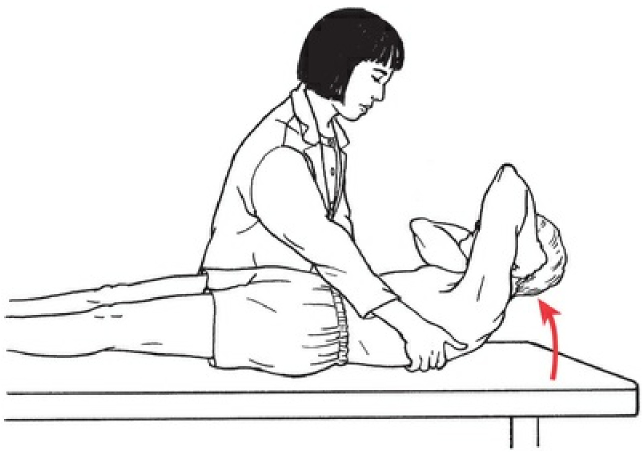

FIGURE 4.28

Substitution

If the pectoralis major is active (inappropriately) in this test of trunk rotation at any grade, the shoulder will shrug or be raised from the table, and there is limited rotation of the trunk.

Instructions to Patient:

"With your chin pointed to the ceiling, lift your head and shoulders from the table, taking your right elbow toward your left knee. Then, with your chin pointed to the ceiling, lift your head and shoulders from the table, taking your left elbow toward your right knee."

Grading

Grade 5:

The scapula corresponding to the side of the external oblique function must clear the table for a Grade 5.

Grade 4

Position of Patient:

Supine with arms crossed over chest.

Test:

Other than patient's arm position, all other aspects of the test are the same as for Grade 5. The test is done first to one side (Fig. 4.29) and then to the other.

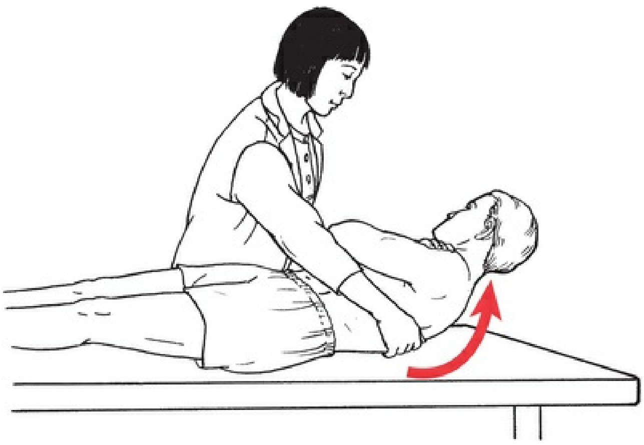

FIGURE 4.29

Grade 3

Position of Patient:

Supine with arms outstretched above plane of body.

Test:

Other than patient's arm position, all other aspects of the test are the same as for Grade 5. The test is done first to the left (Fig. 4.30) and then to the right (Fig. 4.31).

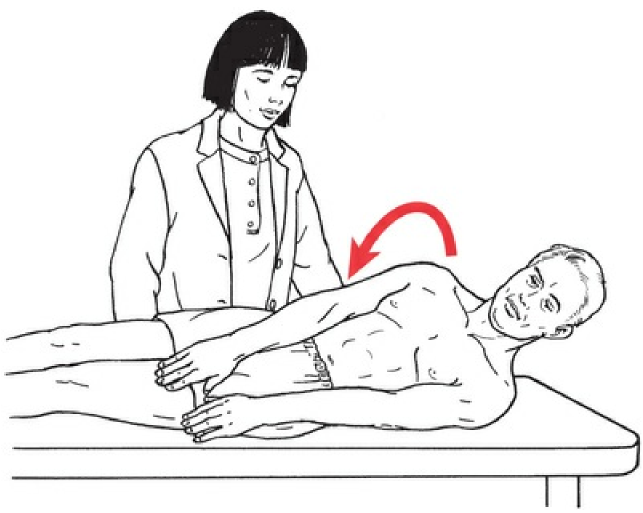

FIGURE 4.30

FIGURE 4.31

Grading

Grade 3:

Patient raises the scapula off the table. The therapist may use one hand to check for scapular clearance (Fig. 4.32).

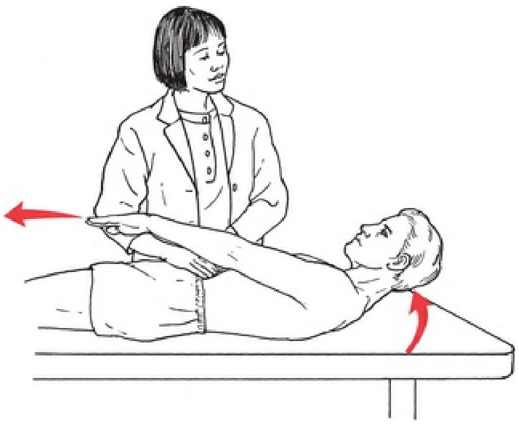

FIGURE 4.32

Grade 2

Position of Patient:

Supine with arms outstretched above plane of body.

Instructions to Therapist:

Stand at level of patient's waist. Palpate the external oblique first on one side and then on the other, with one hand placed on the lateral part of the anterior abdominal wall distal to the rib cage (see Fig. 4.32). Continue to palpate the muscle distally in the direction of its fibers until reaching the ASIS.

At the same time, palpate the internal oblique muscle on the opposite side of the trunk. The internal oblique muscle lies under the external oblique, and its fibers run in the opposite diagonal direction.

Therapists may remember this palpation procedure better if they think of positioning their two hands as if both hands were to be in the pants pockets or grasping the abdomen in pain. (The external obliques run from out to in; the internal obliques run from in to out.)

Instructions to Patient:

"Keep your chin pointed to the ceiling while you lift your head, reach toward your right knee." (Repeat to left side for the opposite muscle.)

Test:

Patient attempts to raise body and turn toward the right. Repeat toward left side.

Grading

Grade 2:

Patient is unable to clear the inferior angle of the scapula from the table on the side of the external oblique being tested. However, the therapist must be able to observe depression of the rib cage during the test activity.

Grade 1 and Grade 0

Position of Patient:

Supine with arms at sides. Hips flexed with feet flat on table.

Instructions to Therapist:

Support patient's head as patient attempts to turn to one side (Fig. 4.33). (Turn to the other side in a subsequent test.) Under normal conditions, the abdominal muscles stabilize the trunk when the head is lifted. In patients with abdominal weakness the supported head permits the patient to recruit abdominal muscle activity without having to overcome the entire weight of the head.

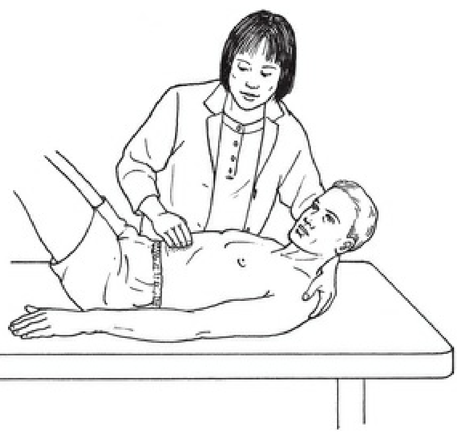

FIGURE 4.33

One hand palpates the internal oblique on the side toward which the patient turns (not illustrated) and the external oblique on the side away from the direction of turning (see Fig. 4.33). The therapist assists the patient to raise the head and shoulders slightly and turn to one side. This procedure is used when abdominal muscle weakness is profound.

Instructions to Patient:

"Try to lift up and turn to your right." (Repeat for turn to the left.)

Test:

Patient attempts to flex trunk and turn to either side.

Grading

Grade 1:

The therapist can see or palpate muscular contraction.

Grade 0:

No discernable muscle contraction from the obliquus internus or externus muscles.

Suggested Exercises for Abdominals[20]

- Abdominal slide (prone with hand roller)
- Torso Track®
- Ab roller (oblique)
- Crunch (straight and oblique)

Core Tests

Core Strength, Stability, and Endurance

Core strength and stability are important components of nearly every gross motor activity and, as such, deserve to be understood from the perspective of testing. Risk for injury is impacted by delays in core muscle activation, decreased muscle recruitment, muscle fatigue, neuromuscular imbalance, impaired proprioception, and delayed reflex responses.[21] The purpose of the core musculature is to provide trunk stability (stiffness) through intra-abdominal pressure and compression of the spinal segments and to allow movement in all directions.[22] Trunk stiffness is necessary to create anticipatory postural adjustments such as adjusting the center of gravity to affect balance and upper and lower extremity joint forces during upright tasks.[23,24] Cocontraction on the anterior and posterior aspect of the trunk increases intra-abdominal pressure and generates greater trunk stiffness.[22]

Core stability is defined as the ability to use muscular strength and endurance to control the spine over the pelvis and leg when performing functional and athletic activities.[25,26] Core stability requires coordination in addition to core strength and endurance.[27] No one muscle contributes more than 30% to the overall stability of the lumbar spine in a variety of loading conditions.[28] Therefore there is no one single most important stabilizing muscle.[29] The core muscles (Fig. 4.34) are composed of a mixture of fast and slow twitch muscle fibers, although slow twitch fibers dominate the lumbar paravertebral muscles.[30] The back extensors have more capillaries than nonpostural muscles, such as triceps brachii. The deep stabilizing muscles are also made up of slow twitch fibers. Endurance testing may be more appropriate than pure strength testing for these core muscles.[30] Although slow twitch muscles may be better suited to endurance-type testing, the combined core muscles are made up of both slow and fast twitch muscles, and thus there is no one endurance test for the core.[31] These muscles respond to changes in posture, external loading, and spinal intersegmental movement. The global superficial muscles, long muscles capable of generating large movements and torque, are made up of fast twitch fibers. Cocontraction of the internal oblique and transversus abdominis increases intra-abdominal pressure and stiffness of the spinal segments, resulting in increased spinal stability.[32] It takes only 5% to 10% of maximal abdominal and multifidi contraction to stiffen the spine.

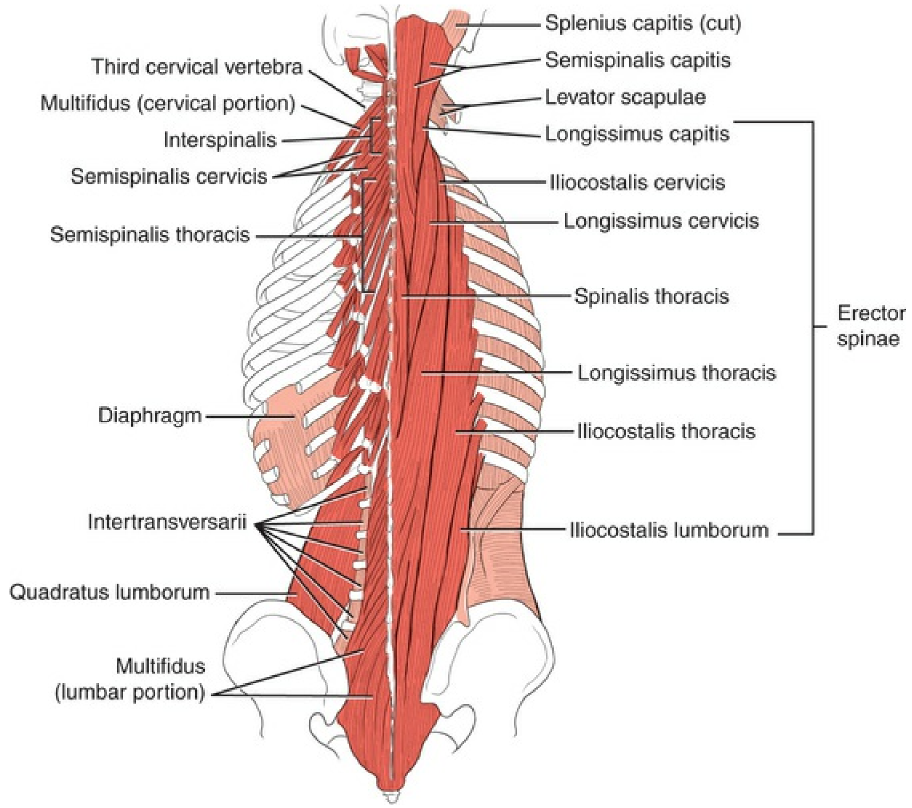

FIGURE 4.34

Endurance of the core musculature may be more important to function than pure strength.[33]

Some of the muscles that make up the core are not amenable to individual muscle testing and therefore are tested as *part* of the core. Others form individual and specific functions and can be tested individually (Fig. 4.35). However, when testing the core, all of these muscles are active (Table 4.6).

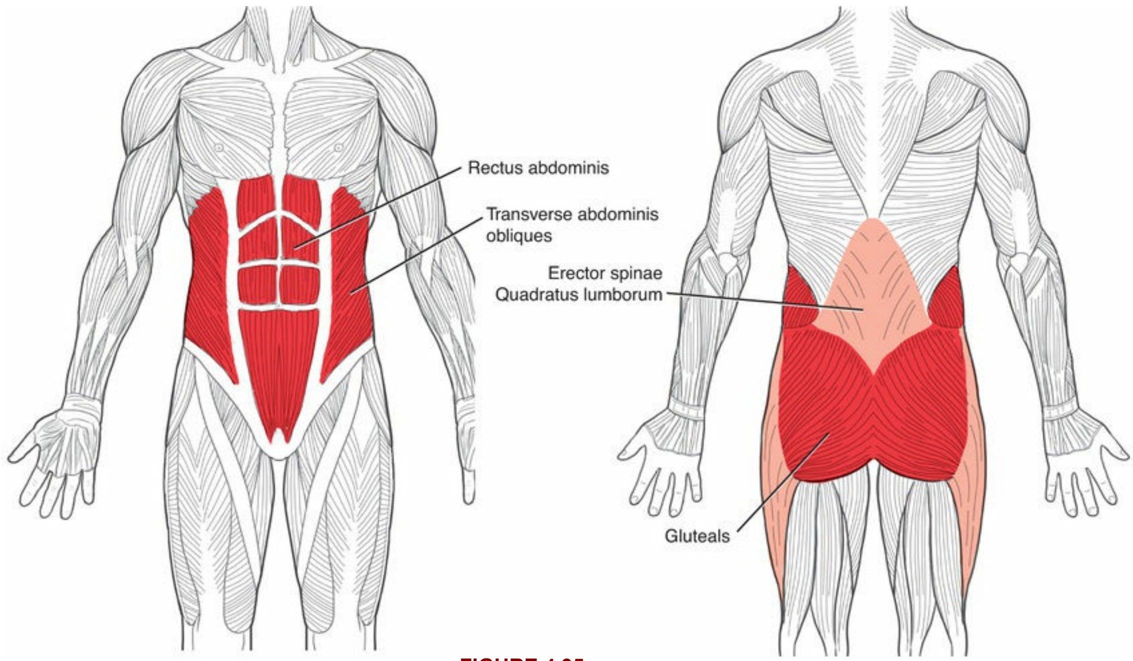

FIGURE 4.35

Table 4.6

MUSCLES COMPRISING THE CORE[22]

Sagittal Plane	Contribution	Frontal Plane	Contribution
Rectus Abdominis	Active in trunk flexion and in combination with the hamstrings; rotates the pelvis posteriorly	Gluteus medius	Primary lateral stabilizer of the hip
Transversus abdominis	With assistance from the multifidus, increase spinal stiffness and raise intra-abdominal pressure	Gluteus minimus	Primary lateral stabilizer of the hip
Erector spinae		Quadratus lumborum	Stiffens the spine and may be active in all upright activities
Multifidus		Adductor magnus	All of the medial muscles maintain static alignment in the frontal plane
Gluteus maximus	Transfers forces from the lower extremity (LE) to the trunk	Adductor longus	
Hamstrings		Adductor brevis	
		Pectineus	

Prone Plank Test

The prone plank test activates core musculature. Correct form consists of maintaining the spine in a neutral position while maintaining scapular adduction and a posterior pelvic tilt.[34] An anterior pelvic tilt reduces EMG activation.[34]

Purpose:

The plank is a superb challenge to the abdominals and muscles of the shoulder girdle, particularly the pectoralis major and minor, serratus anterior, anterior deltoid, supraspinatus and infraspinatus.

Position of Patient:

Prone on floor or mat.

Instructions to Therapist:

From prone, ask patient to lift body weight onto toes and forearms. Elbows should be under the shoulders, with scapulae adducted and hips level with spine like a "plank" (Fig. 4.36). Assess patient's ability to assume a plank position. If successful, explain test to patient.

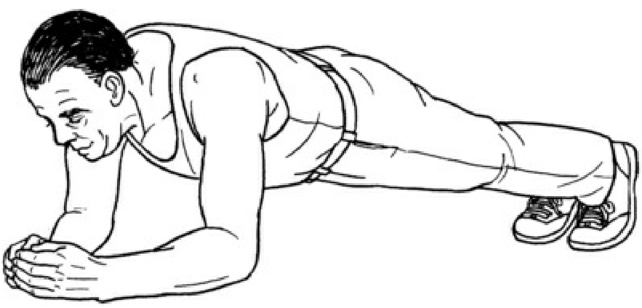

FIGURE 4.36

Time the effort (Table 4.7).

Table 4.7

PERCENTILE SCORES BY SEX AND PERCENTILE SCORES BY SPORT STATUS[35]

Percentile	TIME TO FATIGUE IN THE PLANK TEST (SECONDS)			
	Male (n = 194)	Female (n = 275)	Non-Varsity (n = 109)	Varsity (n = 361)
90th	201	142	151	200
80th	157	108	123	178
70th	137	95	106	149
60th	122	84	94	123
50th	110	72	83	104
40th	97	63	71	92
30th	89	58	62	82
20th	79	48	53	66
10th	62	35	37	59

Instructions to Patient:

"Raise your yourself onto your forearms and toes. Keep your body completely straight. Suck your belly button into your spine" (see Fig. 4.36).

Scoring

A full plank position should be held for 120 seconds to be considered a Grade 5 test. Hold times of less than 90 seconds are Grade 4. Ability to assume the test position but unable to hold results in a Grade 3. The alternate form (described later) is scored a Grade 2. The table that follows contains norms for 471 college students and varsity athletes (mean age, 20 years):

Alternate Form of Plank Testing

For a patient not able to do a full plank, ask the patient to flex the knees and hips and lift the body onto forearms and knees. The elbows should be in line below the shoulders. The patient must keep the buttocks in line with the spine, forming a straight line from neck to buttocks while on knees. Time the effort. This alternate form should be scored as a Grade 2. Hint: Make sure the pelvis and buttocks are not hiked but in line with the spine. The body must come forward onto the forearms to do this Grade 2 test properly.

Side Bridge Endurance Test

Purpose:

Strength test for core. Quadratus lumborum oblique and transverse muscles are elicited without generating large compression forces on the lumbar spine.[36,37]

Position of Patient:

Side-lying with legs extended, resting on the lower forearm with the elbow flexed to 90°. Upper arm is crossed over chest (Fig. 4.37).

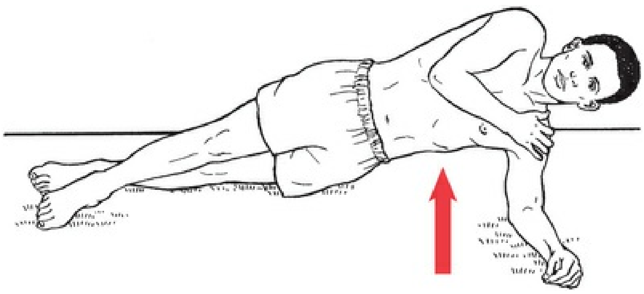

FIGURE 4.37

Instructions to Therapist:

Stand or sit in front of patient. Ask patient to lift the hips off the table, keeping the body in a straight line with the contracted core. Time the effort, observing for quality and quantity of effort. Give patient feedback regarding posture; hips and trunk should be level throughout the test (see Fig. 4.37).

Test:

Patient lifts hips off the table, holding the elevated position in a straight line with the body on a flexed elbow. This position is maintained until the patient loses form, fatigues, or complains of pain. The therapist times the effort.

Instructions to Patient:

"When I say 'go!' lift your hips off the table, keeping them in a straight line with your body for as long as you can. I will be timing you."

Scoring:

Record the best time of two trials.

Mean scores for men and women:[38]

Men: 95(±32)s

Women: 75(±32)s

Helpful Hints

- Despite the high reliability of the side bridge test, significant changes in hold times must be observed to confidently assess a true change in strength. Therefore the patient's rating of perceived exertion (RPE) would help to inform clinical decision-making.[33]
- Mean hold times ranged from 20 to 203 seconds (mean, 104.8 seconds) for the right side bridge test and from 19 to 251 seconds (mean, 103.0 seconds) for the left side bridge test.[33]
- Exercisers held the side bridge test nearly double the time nonexercisers did (64.9 vs. 31.8 seconds).[39]

Timed Partial Curl Up Test[40]

The timed partial curl up test is a standard in the fitness industry and is included here, even though it uses the hook lying position and thus encourages hip flexor activation.

Purpose:

Strength test for abdominals.

Position of Patient:

Supine in hook lying position on a mat with arms at sides, palms facing down, and the middle fingers touching a piece of tape affixed to the surface parallel to the hand. A second piece of tape is affixed 12 cm (4.7 in) further than the initial tape for those younger than 45 years and 8 cm (3.1 in) further for those 45 years and older (Fig. 4.38).

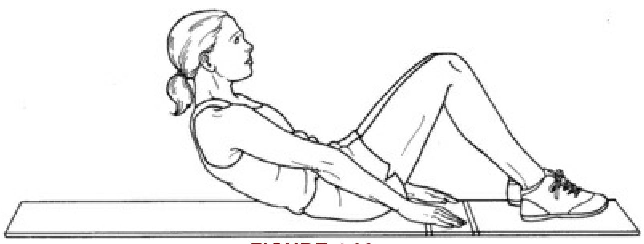

FIGURE 4.38

Instructions to Therapist:

Stand to the side of patient. Ask patient to perform a slow, controlled sit up in time, lifting head and scapulae off the mat, while the middle finger reaches to the second tape. If successful, use a metronome set to 40 beats/min to time repetitions. Ask patient to curl up as many times as possible keeping time with the metronome. The low back should be flattened before curl up.

Test:

The individual does as many curl ups as possible without pausing, to a maximum of 75.

Scoring:

Refer to ACSM Norms for partial curl up (Table 4.8).

Table 4.8

ACSM NORMS For PARTIAL CURL UP

AGE										
	20–29		30–39		40–49		50–59		60–69	
Sex	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**F Female**	**Male**	**F Female**
90th percentile	75	70	75	55	75	55	74	48	53	50
80	56	45	69	43	75	42	60	30	33	30
70	41	37	46	34	67	33	45	23	26	24
60	31	32	36	28	51	28	35	16	19	19
50	27	27	31	21	39	25	27	9	16	13
40	24	21	26	15	31	20	23	2	9	9
30	20	17	19	12	26	14	19	0	6	3
20	13	12	13	0	21	5	13	0	0	0
10	4	5	0	0	13	0	0	0	0	0

ACSM, The American College of Sports Medicine.

Data from Pescatello LS, Ross A, Riebe D, et al. *ACSM's Guidelines for Exercise Testing and Prescription*. 9 ed. Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins; 2014.

Isometric Trunk Flexor Endurance Test[22]

Purpose:

Measure isometric core endurance.

Position of Patient:

Sitting on table with wedge supporting the back at angle of 60° to the table. Hips and knees flexed to 90°, with feet stabilized with a strap. Arms are folded across the chest (Fig. 4.39).

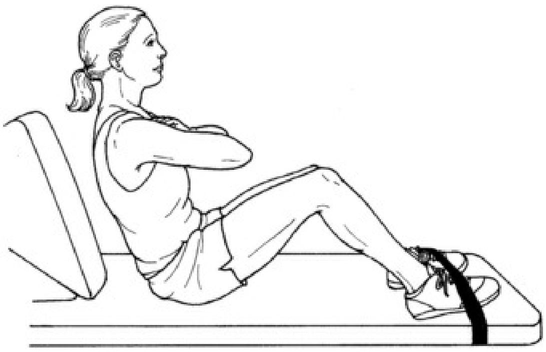

FIGURE 4.39

Instructions to Therapist:

Ask patient to hold test position when the wedge is pulled back 10 cm. Time effort as soon as wedge is pulled back. Terminate test when the patient can no longer maintain the 60° angle independently.

Scoring:

Ages 18 to 55 years (mean, 30 years), mean hold time = 178 seconds.[39]
Exercisers held the test 3 times as long as nonexercisers (186 s vs. 68.25 s).[39]

Front Abdominal Power Test

Purpose:

Assess the power component of core stability prestability and poststability training.

Position of Patient:

Supine on a mat with arms at sides, feet shoulder width apart, and knees bent to 90° (Fig. 4.40A).

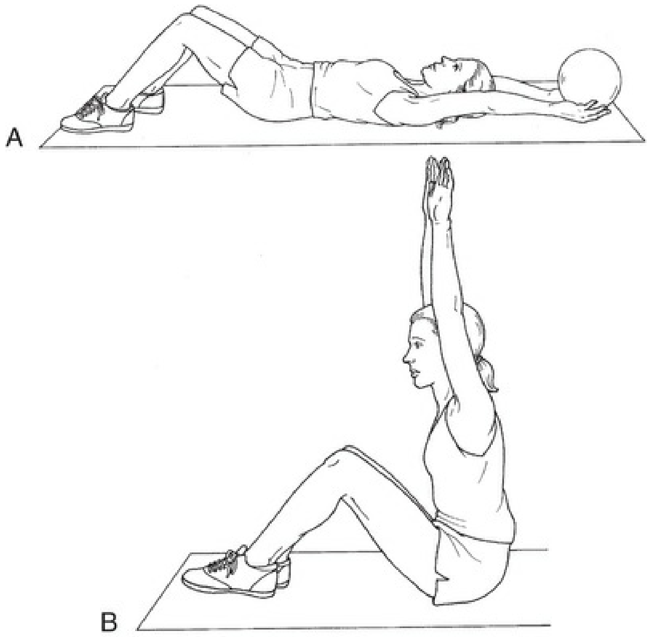

FIGURE 4.40

Instructions to Therapist:

Place a 2-kg medicine ball into the patient's hands. Then ask patient to lift arms overhead and explosively project the medicine ball forward keeping the arms straight. Feet and buttocks should remain on the floor throughout the test. (Note: Feet may be secured manually or with a strap [not shown].) Measure the distance the ball was projected from the tips of the feet to the point where the ball landed. Patient should be sitting upright after the ball is thrown (Fig. 4.40B).

Scoring:

1.5 to 2 m was recorded in a group of 20-year-old men and women (standard error of the mean [SEM], 24 cm).[41,42]

Unilateral Supine Bridge Test[43]

Purpose:

The unilateral supine bridge test (USBT) assesses lumbopelvic neuromuscular control. This test was found to be correlated with lab-based biomechanical measures of isolated core stability.

Position of Patient:

Supine with arms across chest with knees in hook lying.

Instructions to Therapist:

Stand to side of patient. Ask patient to lift both hips into a double-leg bridge. When neutral spine and pelvis positions are achieved, ask patient to extend one knee so leg is straight and thighs parallel to one another (Fig. 4.41). Ask patient to hold position as long as possible, timing the effort. Test is terminated when patient is no longer able to hold a neutral pelvic position, as noted by a 10° change in transverse or sagittal plane alignment. Perform two trials, and average results.

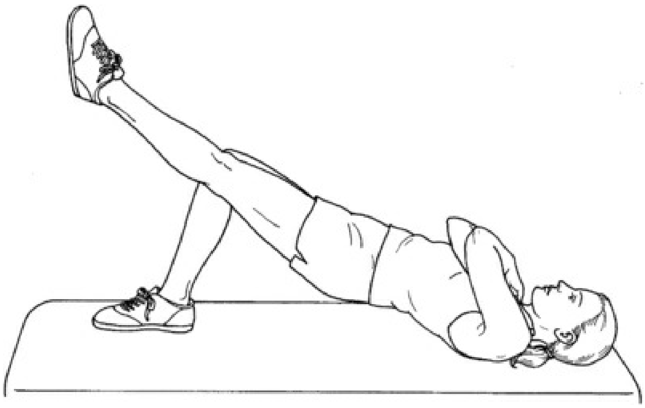

FIGURE 4.41

Scoring:

A sample of 20 healthy male volunteers (mean age, 25.7 years) held test position for an average of 23.0 seconds (16.5) with range of 3.1 to 59.5 seconds.[43]

Suggested Exercises for Core Strengthening

- The side bridge, lateral step up, lunge, and quadruped with arm and leg lift have been found to be effective exercises for increasing overall core strength. These exercises have EMG amplitude greater than 45% maximum voluntary isometric contraction. 45%–50% of one repetition maximum correlates with an increase in strength.[44]
- Longissimus thoracis and lumbar multifidus are most active during bridging, side bridging, unilateral bridging, and quadruped opposite arm/lower extremity lift.[44]
- External oblique and rectus abdominis are most active during prone bridging and side bridging.[44]
- Side bridging was optimal for lower abdominal muscle activation.[44]
- Superman exercise produced greatest activation of back stabilizers.[44]
- Transversus abdominis (TrA) activity by fine wire EMG was greatest during the prone plank with contralateral arm and leg lift with maximum voluntary contractions recorded as 50% or less; indicating the transversus abdominis activation may be best achieved through low-load exercises focusing on motor learning and control.[45]
- Rectus abdominis activity was found to be highest in a curl up exercise on an unstable surface, such as a BOSU ball, with maximum voluntary contraction (MVC) of approximately 50%.[45]

Quiet Inspiration

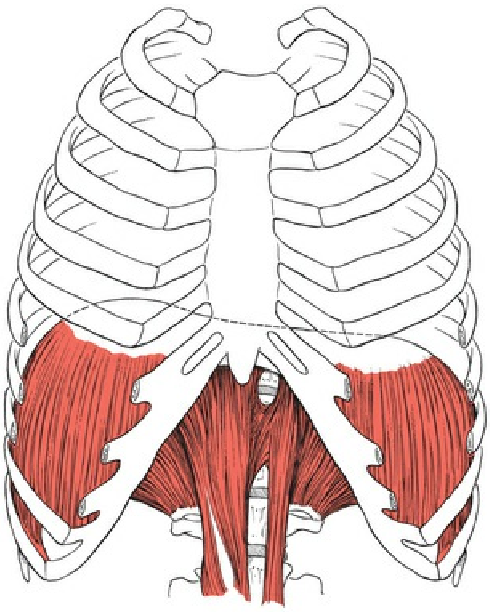

FIGURE 4.42

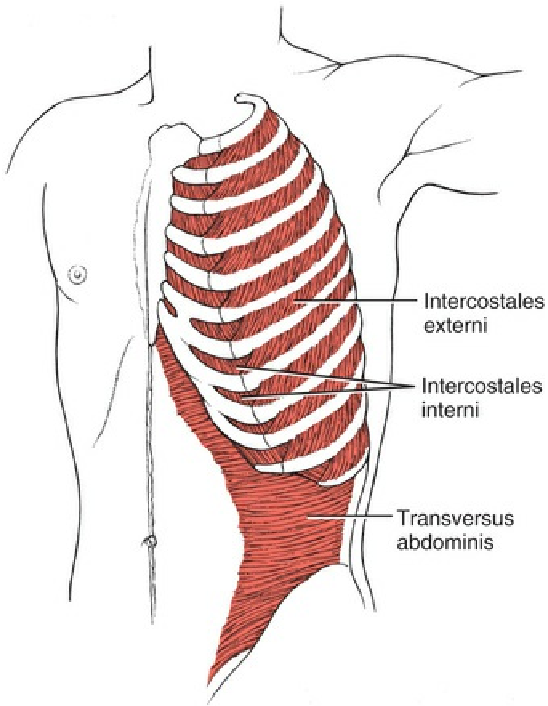

FIGURE 4.43

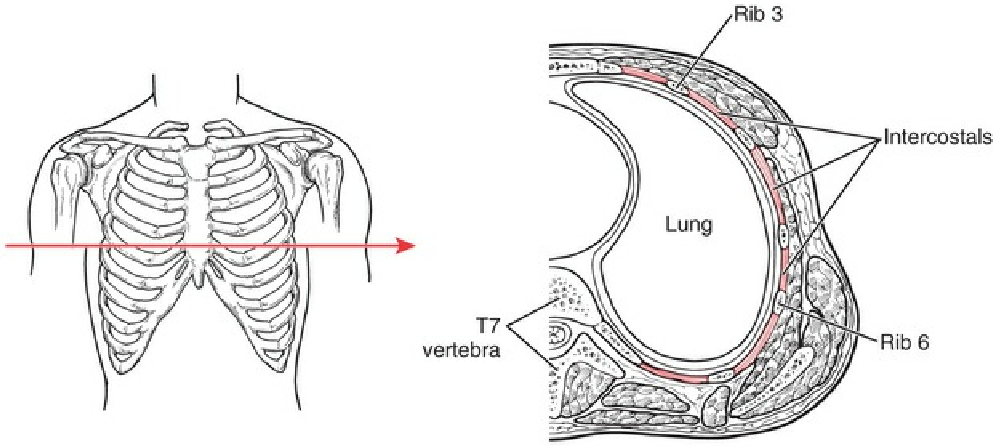

FIGURE 4.44

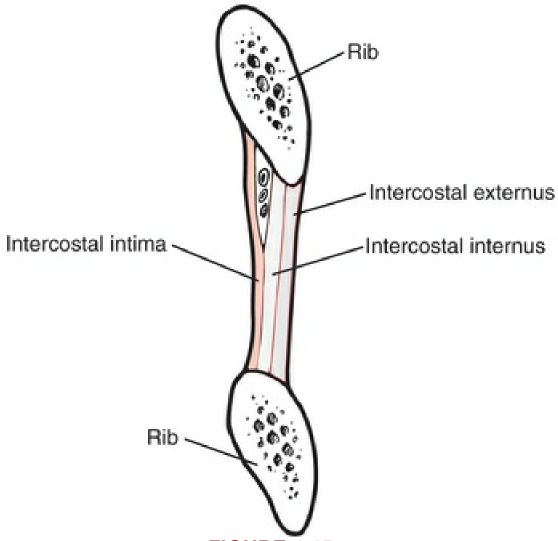

FIGURE 4.45

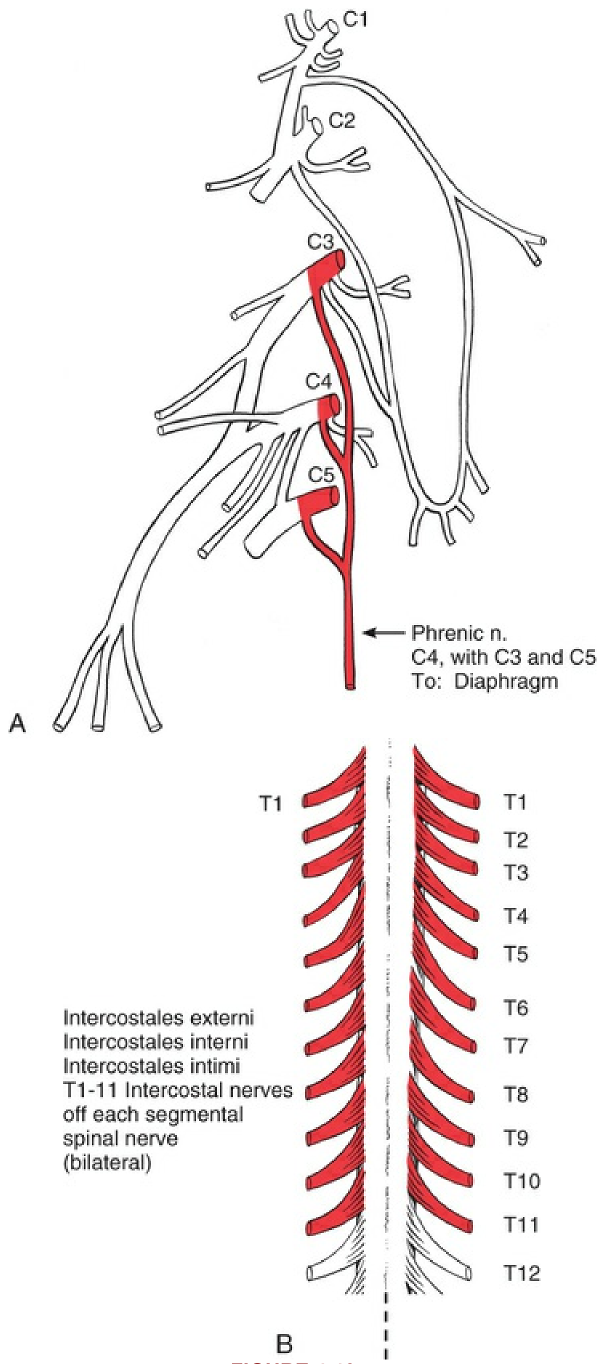

FIGURE 4.46

Range of Motion

Normal range of motion of the chest wall during quiet inspiration is approximately 0.75 inches, with gender variations. Normal chest expansion in forced inspiration varies from 2.0 to 2.5 inches at the level of the xiphoid.[46]

Table 4.9

MUSCLES OF QUIET INSPIRATION

I.D.	Muscle	Origin	Insertion	Function
101	**Diaphragm**	Formed of 3 parts	Fibers all converge on central tendon of	*Inspiration:* Contraction of the diaphragm with the lower ribs fixed draws the

		from the circumference of the thoracic outlet Sternal: Xiphoid Costal: Ribs 7–12 Lumbar: L1-L3 vertebrae	diaphragm; middle of central tendon is below and partially blended with pericardium	central tendon downward and forward during inspiration This increases the vertical thoracic dimensions and pushes the abdominal viscera downward It also decreases the pressure within the thoracic cavity, forcing air into the lungs through the open glottis by the higher pressure of the atmospheric air These events occur along with intercostal muscle action, which elevates the ribs, sternum, and vertebrae, increasing the anteroposterior and transverse thoracic dimensions for the inspiratory effort The diaphragm adds power to expulsive efforts: lifting heavy loads, sneezing, coughing, laughing, parturition, and evacuation of bladder and bowels These activities are preceded by deep inspiration *Expiration:* Passive relaxation allows the half-dome to ascend, thus decreasing thoracic cavity volume and increasing its pressure
102	Intercostales externi (11 pairs)	Ribs 1–11 (lower borders and tubercles; costal cartilages)	Ribs 2–12 (upper margins of rib below; last 2 end in free ends of the costal cartilages) External intercostal membrane	The muscles of respiration are highly coordinated between abdominal and thoracic processes with the diaphragm being the major muscle of inspiration, accounting for about $\frac{2}{3}$ of vital capacity The external intercostals are more active in inspiration than expiration but work closely with the internal intercostals to stiffen the chest wall, preventing paradoxical motion during descent of the diaphragm Elevation of ribs in inspiration There are data to support this claim for the upper four or five muscles, but the more dorsal and lateral fibers of the same muscles also are active in early expiration It is possible that the activity of the intercostals during respiration varies with the depth of breathing[47] Depression of the ribs in expiration (supporting data sparse) Rotation of thoracic spine to opposite side (unilateral) Stabilization of rib cage
103	Intercostales interni (11 pairs)	Sternum (anterior) Ribs 1–11 (ridge on inner surface) Costal cartilages of same rib Internal intercostal membrane	Upper border of rib below Fibers run obliquely to the external intercostals	Not as strong as the external intercostals Elevation of ribs in inspiration This may be true at least for the 1st to 5th muscles The more lateral muscle fibers run more obliquely inferior and posterior and are most active in expiration[47] Stabilization of rib cage
104	Intercostales intimi (innermost intercostals) Often absent	Ribs 1–11 (costal groove)	Rib below (upper margin) Fibers run in same pattern as internal intercostals	Presumed to be identical to intercostales interni
107	Levatores costarum (12 pairs)	C7-T11 vertebrae (transverse processes, tip)	Rib below vertebra of origin (external surface)	Elevation of ribs in inspiration (disputed) Lateral bending of spine
80	Scalenus anterior	C3-C6 vertebrae (transverse processes, anterior tubercles)	1st rib (scalene tubercle)	Flexion of cervical spine (both muscles) Elevation of 1st rib in inspiration Rotation of cervical spine to same side Lateral bending of neck to same side
81	Scalenus medius	C2 (axis)-C7 vertebrae (transverse processes, posterior tubercles) C1 (atlas) sometimes	1st rib (superior surface)	Cervical flexion (weak) Lateral bending of cervical spine to same side Elevation of 1st rib in inspiration Cervical rotation to same side
82	Scalenus posterior	C4-C6 vertebrae (transverse processes posterior tubercle, variable)	2nd rib (outer surface)	Cervical flexion (weak) Elevation of 2nd rib in inspiration Lateral bending of cervical spine to same side (accessory) Cervical spine rotation to same side
Others				
131	Pectoralis major (arms fixed)			

Diaphragm

The diaphragm is under voluntary control via the efferent fibers of the left and right phrenic nerves. This voluntary control can be overridden by reflex activity. Contraction of the diaphragm causes the diaphragm to descend, increasing volume and decreasing pressure within the thoracic cavity. This pressure change creates a pressure gradient that results in movement of air into the airways. As the diaphragm descends, abdominal viscera are compressed and intraabdominal pressure increases. Once the viscera cannot be displaced further, additional contraction of the fibers of the diaphragm causes the lower ribs to move in a cephalad and lateral direction, producing a so-called bucket-handle motion.

Preliminary Examination

Uncover the patient's chest and abdominal area so that the motions of the chest and abdominal walls can be observed. Watch the normal respiration pattern and observe differences in the motion of the chest wall and (epigastric) area and note any contraction of the neck muscles and the abdominal muscles.

The epigastric rise and flaring of the lower margin of the rib cage during inspiration indicate that the diaphragm is active. During quiet inspiration, epigastric rise reflects the movement of the diaphragm descending over one intercostal space.[48,49] In deeper inspiratory efforts, the diaphragm may move across three or more intercostal spaces. The rise on both sides of the linea alba should be symmetric.

An elevation and lateral expansion of the rib cage are indicative of intercostal activity during inspiration. Exertional chest expansion measured at the level of the xiphoid process is 2.0 to 2.5 inches (the expansion may exceed 3.0 inches in more active young people and athletes).[50]

Measurement

Maximum inspiratory pressure (MIP) is the measurement of strength of inspiratory muscles.

Measurements of MIP and maximal expiratory pressure (MEP) may serve as a means of measuring ventilatory muscle strength, although not the strength of any single muscle. The MIP reflects the strength of the diaphragm and other inspiratory muscles, whereas the MEP reflects the strength of the abdominal muscles and other expiratory muscles.

Equipment:

Either a manual pressure gauge (Fig. 4.47) or an electronic pressure gauge (Fig. 4.48) is used. Place a new cardboard mouthpiece or a clean rubber mouthpiece with flanges on the device for each patient use.

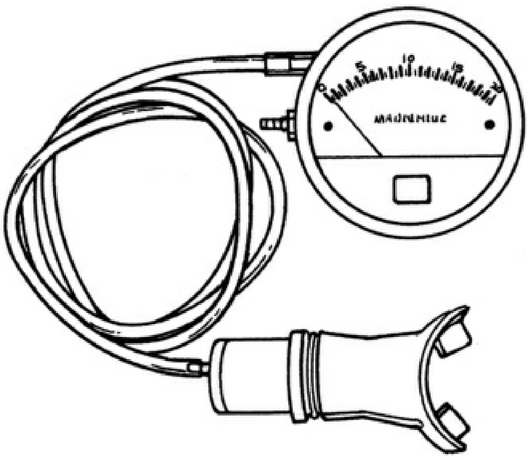

FIGURE 4.47

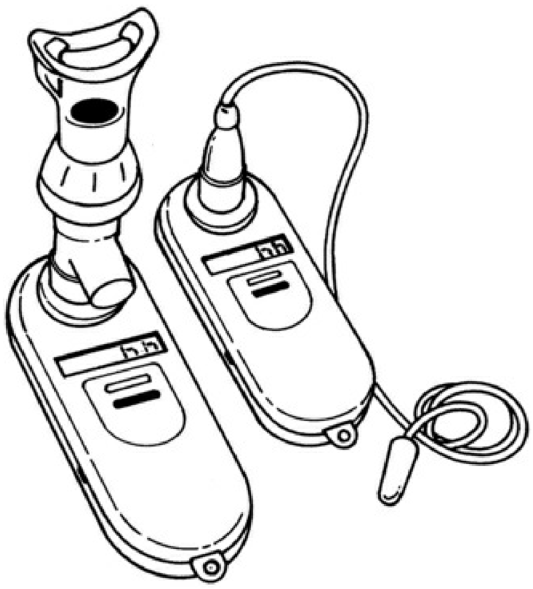

FIGURE 4.48

Maximal Inspiratory Pressure

Position of Patient:

Seated in a chair, with a nose clip applied to the nose (Fig. 4.49).

FIGURE 4.49

Instructions to Therapist:

Stand or sit in front of seated patient so as to read the gauge (see Fig. 4.49; therapist shown at side of patient to better illustrate procedure).

Test:

Demonstrate the maneuver, and then have the patient repeat it. Patient first exhales completely then sucks in as hard as possible. The patient should maintain inspiratory pressure for at least 1.5 seconds; the largest negative pressure sustained for at least 1 second should be recorded. Allow the patient to rest for approximately 1 minute and then repeat the maneuver five times. Provide verbal or visual feedback after each maneuver, but do not allow trunk flexion or extension during the test. The goal is for the variability among measurements to be less than 10 cm H_2O. Measurements should be rounded to the nearest 5 cm H_2O.

Instructions to Patient:

"Seal your lips firmly around the mouthpiece, exhale slowly and completely, and then pull in hard, like you are trying to suck up a thick milkshake."

Maximal Expiratory Pressure

Position of Patient:

Seated in a chair, with a nose clip applied to the nose.

Instructions to Therapist:

Stand or sit in front of seated patient so as to read the gauge.

Test:

Demonstrate the maneuver, and have the patient repeat it. Patient first inhales completely, then blows out as hard as possible. The patient should maintain expiratory pressure for at least 1.5 seconds. The largest positive pressure sustained for at least 1 second should be recorded. Allow the patient to rest for approximately 1 minute and then repeat the maneuver five times. Provide verbal or visual feedback after each maneuver but do not allow trunk flexion or extension during the test. The goal is for the variability among measurements to be less than 10 cm H_2O. Measurements should be rounded to the nearest 5 cm H_2O.

Instructions to Patient:

"I want you to inhale completely as you push the mouthpiece firmly against your lips and teeth and then push (or blow) as hard as possible, like you are trying to fill a very stiff balloon."

Grading

An MIP of ≥80 cm H_2O usually excludes the presence of inspiratory muscle weakness.[51]

Helpful Hint

Some patients with orofacial muscle weakness may not be able to obtain a good seal with the lips. It is permissible to allow such patients to use their hand to press their lips against the mouthpiece during each maneuver. Alternatively, the therapist can press the patient's lips against the mouthpiece as necessary to obtain a good seal or a face mask interface can be substituted.

Intercostals

There is no method of direct assessment of the strength of the intercostal muscles.

The scalene muscles, as assessed via needle EMG examination, are active with every inspiratory effort and should be considered a primary muscle of inspiration.[52]

Diaphragmatic function can also be measured through ultrasound. This is an examination technique that is not typically included in entry-level education. A machine with a microconvex, 2 to 4 MHz probe is used.[53] Two measurements can be used, both of which relate indirectly to the strength of the diaphragm. One is diaphragmatic excursion, measured using an anterior subcostal approach between the anterior axillary and midclavicular lines. A cutoff of less than 25 mm has been suggested as an indicator of severe diaphragmatic dysfunction.[54] The second is the thickening fraction (TF). Inspiratory and expiratory thicknesses are measured where the diaphragm is in contact with the rib cage in the eighth or ninth intercostal space between the mid and anterior axillary lines. The TF is measured as a percentage of the end-expiratory thickness. A TF less than 20% is likely to indicate severe dysfunction.[55]

Suggested Exercise for Inspiratory Training

Weak inspiratory muscles can be strengthened through targeted inspiratory muscle training (IMT). Training principles are similar to those used to increase the strength of any other muscle. Patients either inhale through a mouthpiece with an adjustable diameter opening or using a device with a spring-loaded valve that does not open to allow airflow until a threshold pressure is reached. This type of device, commonly referred to as threshold trainer, has the advantage of producing a load that is independent of the airflow rate generated by the user.[56] A typical training program would be performed for 15 minutes, twice daily, five to seven times per week, at an intensity of 30%-50% of MIP.[57]

Using abdominal weights to produce resistance can be effective.[58]

In this exercise the patient is supine and a predetermined weight is placed on the stomach. The goal is to have the patient elevate the weight with each inspiration.

Forced Expiration

The cough is an essential procedure to maintain airway patency and to clear the pharynx and bronchial tree when secretions accumulate. A cough may be a reflex or voluntary response to irritation anywhere along the airway downstream from the nose. The three phases of cough—inspiration, compression, and forced expiration—are mediated by the muscles of the thorax and abdomen, as well as those of the pharynx, larynx, and tongue. The deep inspiratory effort is supported by the diaphragm, intercostals, and arytenoid abductor muscles (the posterior cricoarytenoids), permitting inhalation of more than 1.5 L of air.[59] The palatoglossus and styloglossus elevate the tongue and close off the oropharynx from the nasopharynx. The compression phase requires the lateral cricoarytenoid muscles to adduct and close the glottis.

The strong expiratory movement is augmented by strong contractions of the thorax muscles, particularly the latissimus dorsi and the oblique and transverse abdominal muscles. The abdominal muscles raise intra-abdominal pressure, forcing the relaxing diaphragm up and drawing the lower ribs down and medially. Elevation of the diaphragm raises the intrathoracic pressure to approximately 200 mm Hg, and the explosive expulsion phase begins with forced abduction of the glottis.

Coughing often is used as the clinical test for forced expiration. An effective cough requires the use of all muscles of active expiration in contrast to quiet expiration, which is the passive relaxation of the muscles of inspiration. However, it must be recognized that a patient may not have an effective cough because of inadequate laryngeal control or low vital capacity.

Grading

The usual muscle test grades do not apply here; thus the following scale to assess the cough is used:

Functional:

Normal or only slight impairment:

- Crisp or explosive expulsion of air
- Volume is sharp and clearly audible
- Able to clear airway of secretions

Weak Functional:

Moderate impairment that affects the degree of active motion or endurance:

- Decreased volume and diminished air movement
- Appears labored
- May take several attempts to clear airway

Nonfunctional:

Severe impairment:

- No clearance of airway
- No expulsion of air
- Cough attempt may be nothing more than an effort to clear the throat

Zero:

Cough is absent.

Helpful Hints

- It is generally accepted that if an individual's forced vital capacity (FVC) is ≥60% of the predicted value, the inspired volume is sufficient to generate a functional, effective cough.[60]
- FVC can be measured with a simple spirometer (Fig. 4.50). A forced expiratory volume ≥60% of the individual's measured FVC should be adequate for sufficiently forceful expulsion.[61]

FIGURE 4.50

- A peak cough flow rate of 160 L/min is highly predictive of successful secretion clearance and subsequent extubation and decannulation in patients with neuromuscular disease.[62]

Table 4.10
MUSCLES OF FORCED EXPIRATION

I.D.	Muscle	Origin	Insertion	Function
110	**Obliquus externus abdominis**	Ribs 5–12 (interdigitating on external and inferior surfaces)	Iliac crest (outer border) Aponeurosis from 9th costal cartilage to ASIS; both sides meet at midline to form linea alba Pubic symphysis (upper border)	Flexion of trunk (bilateral muscles) Tilts pelvis posteriorly Elevates pelvis (unilateral) Rotation of trunk to opposite side (unilateral) Lateral bending of trunk (unilateral) Support and compression of abdominal viscera, counteracting effect of gravity on abdominal contents Assists defecation, micturition, emesis, and parturition (i.e., expulsion of contents of abdominal viscera and air from lungs) Important accessory muscle of forced expiration (during expiration it forces the viscera upward to elevate the diaphragm)
111	**Obliquus internus**	Iliac crest (anterior ⅔ of intermediate line) Thoracolumbar fascia Inguinal ligament (lateral ⅔ of upper aspect)	Ribs 9–12 (inferior border and abdominis cartilages by digitations that appear continuous with internal intercostals) Ribs 7–9 (cartilages) Aponeurosis to linea alba Pubic crest and pecten pubis	
112	Transversus abdominis	Inguinal ligament (lateral ⅓) Iliac crest (anterior ⅔, inner lip) Thoracolumbar fascia Ribs 7–12 (costal cartilages interdigitate with diaphragm)	Linea alba (blends with broad aponeurosis) Pubic crest and pecten pubis (to form falx inguinalis)	Constricts (flattens) abdomen, compressing the abdominal viscera and assisting in expelling their contents Forced expiration
113	Rectus abdominis	Arises via 2 tendons: Lateral: pubic crest (tubercle) and pecten pubis Medial: symphysis pubis (ligamentous covering)	Ribs 5–7 (costal cartilages) Costoxiphoid ligaments	Flexion of spine (draws symphysis and sternum toward each other) Posterior tilt of pelvis With other abdominal muscles, compresses abdominal contents
103	Intercostales interni	Ribs 111 (inner surface) Sternum (anterior) Internal intercostal membrane	Ribs 2–12 (upper border of rib below rib of origin)	Not as strong as the external intercostals Elevation of ribs in inspiration This may be true at least for the 1st to 5th muscles The more lateral muscle fibers run more obliquely inferior and posterior and are most active in expiration[47] Stabilization of rib cage
130	Latissimus dorsi	T6-T12 and all lumbar and sacral vertebrae (spinous processes via supraspinous ligaments) Iliac crest (posterior) Thoracolumbar fascia Ribs 9–12 (interdigitates with external abdominal oblique)	Humerus (floor of intertubercular sulcus) Deep fascia of arm	Extension, adduction, and internal rotation of shoulder Hyperextension of spine (muscles on both sides), as in lifting The muscle is most powerful in overhead activities (such as swimming [downstroke] and climbing), crutch walking (elevation of trunk to arms, i.e., shoulder depression), or swinging Adducts raised arm against resistance (with pectoralis major and teres major)

				It is very active in strong expiration, as in coughing and sneezing, and in deep inspiration Elevation of pelvis with arms fixed
Other				
106	Transversus thoracis			

ASIS, Anterior superior iliac spine.

Pelvic Floor

The pelvic floor muscles form the "floor" of the pelvis and perform four important functions:

Supportive: by counteracting passive gravitational pull and dynamic intra-abdominal pressures impacting the pelvic viscera in conjunction with the inner core muscles forming the canister of core stabilization.[63]

Sphincteric: by shortening in an anterosuperior direction, these muscles squeeze off the urethra, vagina, and anorectal junction to maintain urinary and fecal continence.[64]

Sexual: by rhythmically contracting during orgasm to enhance sexual satisfaction.

Postural stabilizer: by working with the transversus abdominis, multifidi, and pulmonary diaphragm, the pelvic floor creates the bottom of the inner core "canister" (Fig. 4.51).

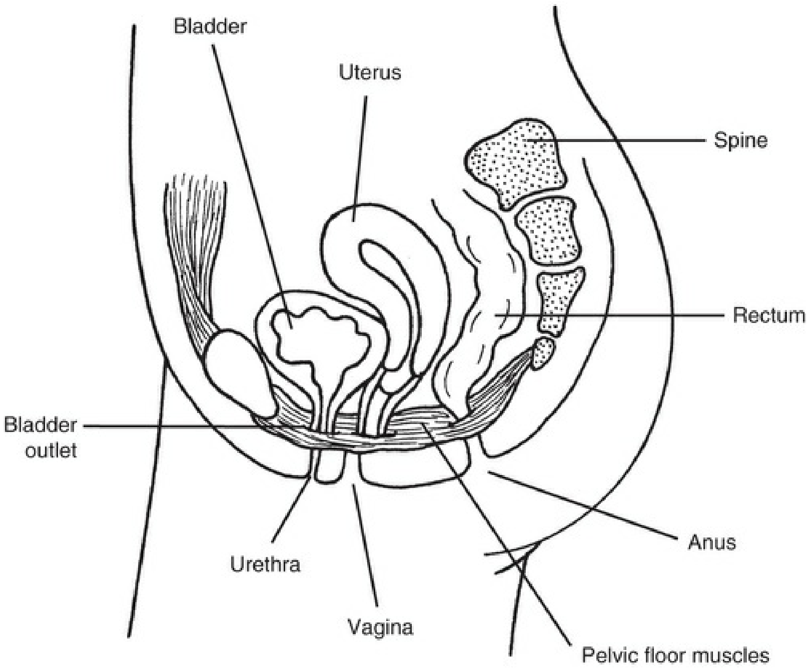

FIGURE 4.51 Pelvic floor muscles serve as a sling for the female organs.

Poor pelvic floor strength is associated with pelvic organ prolapse and urinary or fecal incontinence. Ninety-seven percent of women will experience some level of supportive dysfunction in their lifetime, leading to "falling" of the bladder, rectum, uterus, or small intestine.[65] Urinary or fecal incontinence is experienced by as many as 72% of women of all ages.[66] Fecal incontinence is thought to be grossly underreported because of the associated social stigma. However, urinary incontinence is amenable to treatment, with reports of an 84% success rate using the Kegel exercise (controlled voluntary contractions used to strengthen the pelvic floor).[67]

Sexual dysfunction may be related to weak pelvic floor musculature and urinary incontinence.[68,69] Thirty-one percent of men and 43% of women between the ages of 18 and 59 years report concerns during physical intimacy, some of which are related to urinary incontinence and a weak pelvic floor.[70] Up to 80% of aging women have similar concerns.[71]

The pelvic floor muscles can become weakened from childbirth,[72] poor patterns of muscle recruitment, medical comorbidities such as diabetes, abdominopelvic surgical procedures, constipation, abdominal obesity, chronic cough, hormonal changes, and loss of muscle mass with aging. Because of the frequency of pelvic floor weakness, pelvic floor muscle strength should be routinely assessed to rule out muscle weakness, spasm, or dyscoordination in the presence of lumbopelvic, urologic, gynecologic, sexual, or gastrointestinal dysfunction.

Methods used to assess the strength and function of the pelvic floor muscles include the following:

• Presence of pelvic floor muscle activation: clinical observation, external perineal palpation, vaginal or rectal digital palpation, EMG, and pressure gauges.
• Quantification of pelvic floor muscle strength: manual muscle testing with rectal or vaginal palpation, vaginal cones,[73] and vaginal squeeze pressure.[74]
• Additional visualization of the pelvic floor musculature may be done with abdominal or pelvic two-dimensional ultrasound,[75] ultrasound, and magnetic resonance imaging.[76]

Anatomy of the Pelvic Floor

Muscles of the pelvic floor are difficult to visualize, particularly because most students do not have the opportunity to dissect this region in anatomy class. In both males and females, there are five muscles of the urogenital region that differ in size and disposition in relation to the male and female external genitalia. These five muscles are grouped into superficial and deep layers. Superficial muscles include three portions of the levator ani (puborectalis, pubococcygeus, iliococcygeus) and the ischiococcygeus. Connective tissue and the deep transverse perinei comprise the deep layer (Fig. 4.52).

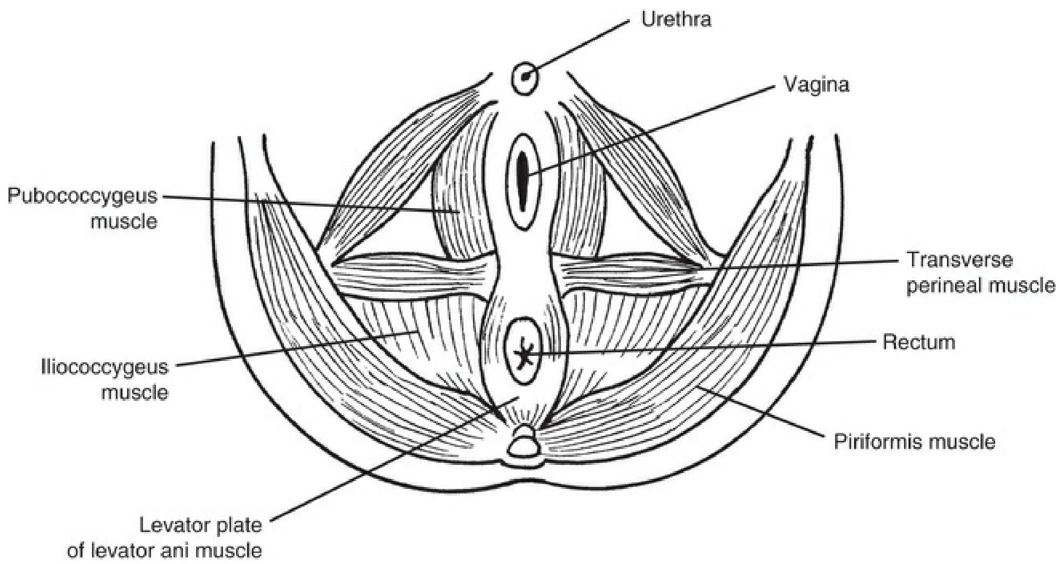

FIGURE 4.52

The superficial layer is the outermost layer; it resembles a sling and is shaped like a figure eight. Although the superficial layer is relatively thin in terms of mass, it is highly sensitive. This area is responsible for controlling the anal and urethral sphincters, so these muscles play an important role in continence. To work effectively, the sphincters need the support of the rest of the pelvic floor, particularly the connective tissue elements. In addition, because the abdominals share the same connective tissue attachments as the pelvic floor musculature, in many women they too need to be strengthened, along with the pelvic floor musculature.

The deep layer of the pelvic floor is the real workhorse of the pelvic floor. The deep pelvic floor muscles have the highest resting muscle tone in the body and play a vital role in movement, posture, and breathing. These muscles must continuously support the weight of the pelvic and abdominal organs when the person is upright (see Fig. 4.51). The deep pelvic floor is sometimes called the pelvic diaphragm. Like its companion, "the roof" or the pulmonary diaphragm, it has minimal sensory innervation and its movement is not felt directly. When it works well, the pelvic floor functions like a well-balanced trampoline and has amazing tensile strength and elasticity. It plays a crucial role in ensuring spinal stability and free locomotion. Deep abdominal muscles in front, the multifidi around the spine, and the pulmonary diaphragm all must work together synergistically with the pelvic diaphragm. Thus "there is no core without the floor" (Table 4.11).

Table 4.11

MUSCLES OF THE PELVIC FLOOR (PERINEUM)

I.D.	Muscle	Origin	Insertion
120	Bulbocavernosus	Surrounds the orifice of the vagina	Blends with sphincter ani externus
121	Ischiococcygeus	Inner surface of the ischial tuberosity	Tendinous aponeurosis attached to the sides and under surface of the crus clitoridis
118	Transversus perinei superficialis (indistinct, often missing)	Medial/anterior ischial tuberosity	Perineal body
119	Transversus perinei profundus	Inner surface ramus of the ischium	Blends into perineal body and vaginal wall
122	Sphincter urethrae	Superior: encircle lower end of the urethra Inferior: transverse perineal ligament	Interlace with fibers from the opposite side
Others			
115	Puborectalis		
115	Levator ani: Puborectalis Iliococcygeus Pubococcygeus		

Testing the Muscles of the Pelvic Floor

Test Description and Procedure

In a separate treatment room the therapist should explain the pelvic exam in total detail. It is not uncommon for therapists to have patients sign a consent form prior to beginning the exam. The patient should be advised that she can stop the exam at any time for any reason. After the patient thoroughly understands the exam, the therapist instructs her to disrobe from the waist down, cover herself with a sheet provided by the therapist, and lie supine on a plinth. The therapist leaves the room while the patient is preparing for the test. After the therapist returns, the patient is asked to roll her legs into external rotation and abduction (hook lying). After the patient is relaxed, the therapist dons sterile gloves that contain no allergens or other potentially irritating material to the patient. The therapist may apply a nonallergenic lubricant to the gloves for patient comfort. While standing slightly to the side of the patient, the therapist moves the sheet drape aside to locate needed landmarks, replaces the drape, and then slowly inserts the middle finger, index and middle finger, or middle and ring finger, into the vagina. If a patient has complaints of pelvic pain, usually only one finger is used. Once fingers are in place, the patient is asked to "pull my fingers up and in" a total of three to four times. Contractions are maintained for 1 to 2 seconds (Fig. 4.53).

FIGURE 4.53

Grading

There are several grading scales, but the scale used most commonly is the Modified Oxford Scale.[77] The Modified Oxford Scale is a 6-point scale in which half numbers of + and − can be added when a contraction is considered to fall between two full grades, so that the scale expands to a 15-point scale (when both + and − are used):

0 = No contraction detected
1 = Flicker
2 = Weak (the patient contracts the pelvic floor muscles well enough to partially encircle the therapist's fingers)
3 = Moderate (the patient fully encircles the therapist's fingers)
4 = Good (the patient fully encircles the therapist's fingers and partially pull the fingers further into the vaginal cavity)
5 = Strong (the patient fully encircles the therapist's fingers with a *strong* contraction *and* pull the fingers fully up and into the vaginal canal)

The Modified Oxford Scale has fair reliability among experienced therapists.[78] Test accuracy may be enhanced with visual examination during the actual manual muscle test. Visual observation can confirm perineal tightening and whether the fingers are drawn up and in, but most therapists do not observe the movement for various reasons.

Perineometer

The perineometer was developed to specifically determine the amount of contractile force a woman can generate with the pelvic floor musculature (Fig. 4.54). The portion of the perineometer that is inserted into the vagina is typically approximately 28 mm in diameter with an active measurement length of approximately 55 mm. Different types of perineometers are available, and each works on the same principle as a blood pressure monitor.

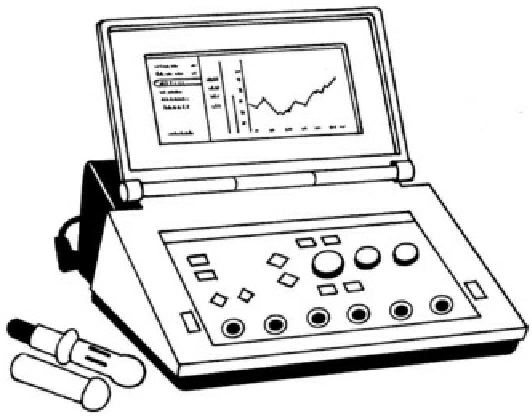

FIGURE 4.54

Perineometer Test

Purpose:

Many women experience incontinence and/or sexual dysfunction, both of which may be a consequence of pelvic floor weakness. The perineometer is a device that was specifically developed to determine the amount of contractile force a woman can generate with the pelvic floor musculature (see Fig. 4.54). Many types of perineometer devices are available and each works on the same principle as a blood pressure monitor.

Position of Patient:

Supine on a plinth with the knees flexed and the hips in some abduction.

Test Procedure:

The perineometer is first covered with a sterile sheath and then inserted into the vagina. A sterile hypoallergenic gel may be used on the sheath. The patient is then asked to perform a Kegel exercise, exerting as much force against the probe as possible (squeezing it). The therapist must make sure the patient is *not* holding her breath while performing the pelvic contraction. The patient performs three contractions with a 10-second rest between each contraction; the therapist records the highest force output or the average of the three. One advantage of the perineometer over manual muscle testing (MMT) is that duration of contraction hold can be determined. The reliability of the perineometer is comparable to that of MMT. Interrater and intrarater reliability have been established.[79]

Instructions to Therapist:

Cover the perineometer with a sterile sheath. A sterile hypoallergenic gel may be used on the sheath. Drape the patient. Explain procedure to patient. With patient supine and hips and knees flexed, insert perineometer into the vagina. After the probe is in place, patient is asked to perform a Kegel exercise, exerting as much force against the probe as possible (squeezing it). Patient should not hold breath during contraction. The patient performs three contractions with a 10-second rest between each contraction.

Instructions to Patient:

"Squeeze as hard as you can against the probe, and hold it. Rest, now repeat."

Scoring

Record the highest force output or the average of the three contractions.

Helpful Hints

One advantage of the perineometer over a manual muscle test is that the duration of the contraction hold can be objectively determined. The reliability of the perineometer is comparable to that of manual muscle testing. Interrater and intrarater reliability have been established.[48]

The Kegel (pronounced KAY-gull) exercise is named after Dr. Arnold Kegel, who designed the exercise to strengthen the pelvic floor muscles, especially the pubococcygeal muscles. The exercise consists of tightening the pelvic floor muscles to stop a stream of urine. Strengthening the pelvic floor muscles increases vaginal tone, thus improving sexual response and limiting involuntary urine secondary to stress incontinence. Kegel exercises are often prescribed following childbirth or during or after menopause.

Risk Management Considerations

Vaginal, rectal, and instrumented testing of the pelvic floor is typically taught at the post-entry level. Given the sensitivity of this examination, there should be a compelling reason to perform it based on the patient's subjective complaint or previous test findings. An appropriate level of patient education to ensure informed consent should also be provided. Before engaging in this new area of practice, therapists should review their state's practice laws to ensure that pelvic floor examination is included within the physical therapist's scope of practice. In addition, each therapist must be able to demonstrate competence through evidence of training specific to pelvic floor rehabilitation, including internal assessment and treatment, before entering this new area of practice.

References

1. Balzini L, Vannucchi L, Benvenuti F, et al. Clinical characteristics of flexed posture in elderly women. *J Am Geriatr Soc*. 2003;51(10):1419–1426.
2. Shirazi-Adl A, Sadouk S, Parnianpour M, et al. Muscle force evaluation and the role of posture in human lumbar spine under compression. *Eur Spine J*. 2002;11(6):519–526.
3. Panjabi MM. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. *J Spinal Disord*. 1992;5:383–389 [discussion 397].
4. Panjabi MM. The stabilizing system of the spine. Part II. Neutral zone and instability hypothesis. *J Spinal Disord*. 1992;5:390–396 [discussion 397].
5. Okubo Y, Kaneoka K, Imai A, et al. Electromyographic analysis of transversus abdominis and lumbar multifidus using wire electrodes during lumbar stabilization exercises. *J Orthop Sports Phys Ther*. 2010;40(11):743–750.
6. Bergmark A. Stability of the lumbar spine. A study in mechanical engineering. *Acta Orthop Scand Suppl*. 1989;230:1–54.
7. Biering-Sørensen F. Physical measurements as risk indicators for low-back trouble over a one-year period. *Spine*. 1984;9:106–119.
8. Demoulin C, Vanderthommen M, Duysens C, et al. Spinal muscle evaluation using the Sørensen test: a critical appraisal of the literature. *Joint Bone Spine*. 2006;73(1):43–50.
9. Moreau CE, Green BN, Johnson CD, et al. Isometric back extension endurance tests: a review of the literature. *J Manip Physiol Ther.*2001;24:110–122.
10. Singh DKA, Bailey M, Lee R. Decline in lumbar extensor muscle strength in older adults: correlation wht age, gender, and spine morphology. *BMC Muscuolskelet Disor*. 2013;14(1):215.
11. Sinaki M, Nwaogwugwu NC, Phillipls BE, et al. Effect of gender, age, and anthropometry on axial and appendicular muscle strength. *Am J Phys Med Rehabi.*2001;80(5):330–338.
12. Adedoyin RA, Mbada CE, Farotimi AO, et al. Endurance of low back musculature: normative data for adults. *J Back Musculoskelet Rehabil*. 2011;24:101–109.
13. Luoto S, Heliovaara M, Hurri H, et al. Static back endurance and the risk of low-back pain. *Clin Biomech (Bristol, Avon)*. 1995;10:323–324.
14. Arab AM, Salavati M, Ebrahimi I, et al. Sensitivity, specificity and predictive value of the clinical trunk muscle endurance tests in low back pain. *Clin Rehabil*. 2007;21(7):640–647.
15. Alaranta H, Hurri H, Heliovaara M, et al. Non-dynamometric trunk performance tests: reliability and normative data. *Scand J Rehabil Med*. 1994;26:211–215.
16. Steele J, Bruce-Low S, Smith D. A review of the specificity of exercises designed for conditioning the lumbar extensors. *Br J Sports Med*. 2015;49:291–297.
17. Kendall FP, McCreary EK, Provance PG. *Muscles, Testing and Function: With Posture and Pain*. Williams & Wilkins: Baltimore, Md; 1993.
18. Ng JFK, Richardson C, Jull GA. Electromyographic amplitude and frequency changes in the iliocostalis lumborum and multifidus muscles during a trunk holding test. *Phys Ther*. 1997;77:954–961.
19. Monfort-Pañego M, Vera-García FJ, Sánchez-Zuriaga D, et al. Electromyographic studies in abdominal exercises: a literature synthesis. *J Manipulative Physiol Ther*. 2009;32(3):232–244.
20. Escamilla RF, McTaggart MSC, Fricklas EJ, et al. An electromyographic analysis of commercial and common abdominal exercises: Implications for rehabilitation and training. *J Orthop Sports Phys Ther*. 2006;36(2):45–57.
21. Cholewicki J, Silfies SP, Shah RA, et al. Delayed trunk muscle reflex responses increase the risk of low back injuries. *Spine*. 2005;30(23):2614–2620.
22. Willson JD, Dougherty CP, Ireland ML, et al. Core stability and its relationship to lower extremity function and injury. *J Am Acad Orthop Surg*. 2005;13(5):316–325.
23. Brown SH, Haumann ML, Potvin JR. The responses of leg and trunk muscles to sudden unloading of the hands: implications for balance and spine stability. *Clin Biomech (Bristol, Avon)*. 2003;18(9):812–820.
24. Hodges PW, Cresswell AG, Daggfeldt K, et al. Three dimensional preparatory trunk motion precedes asymmetrical upper limb movement. *Gait Posture*. 2000;11(2):92–101.
25. Bliss LS, Teeple P. Core stability: the centerpiece of any training program. *Curr Sports Med*

Rep. 2005;4:179e83.
26. Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. *Sports Med*. 2006;36(3):189–198.
27. Liemohn WP, Baumgartner TA, Gagnon LH. Measuring core stability. *J Strength Cond Res*. 2005;19(3):583–586.
28. Cholewicki J, VanVliet JJ 4th. Relative contribution of trunk muscles to the stability of the lumbar spine during isometric exertions. *Clin Biomech (Bristol, Avon)*. 2002;17(2):99–105.
29. McGill SM, Grenier S, Kavcic N, et al. Coordination of muscle activity to assure stability of the lumbar spine. *J Electromyogr Kinesiol*. 2003;13(4):353–359.
30. Jørgensen K. Human trunk extensor muscles physiology and ergonomics. *Acta Physiol Scand Suppl*. 1997;637:1–58.
31. Akuhota V, Ferreiro A, Moore T, et al. Core stability exercise principles. *Curr Sports Med Rep*. 2008;7(1):39–40-44.
32. Stokes IAF, Gardner-Morse MG, Henry SM. Abdominal muscle activation increases lumbar spinal stability: analysis of contributions of different muscle groups. *Clin Biomech (Bristol, Avon)*. 2011;26:797–798-803.
33. Evans K, Refshauge K, Adams R. Trunk muscle endurance tests: reliability, and gender differences in athletes. *J Sci Med Sport / Sports Med Aus*. 2007;10(6):447–455.
34. Cortell-Tormo JM, García-Jaén M, Chulvi-Medrano I, et al. Influence of scapular position on the core musculature activation in the prone plank exercise. *J Strength Cond Res*. 2017;31(8):2255–2262.
35. Strand SL, Hjelm J, Schoepe TC, et al. Norms for an isometric muscle endurance test. *J Hum Kinet*. 2014;40:93–102.
36. Kavcic N, Grenier S, McGill SM. Determining the stabilizing role of individual torso muscles during rehabilitation exercises. *Spine*. 2004;29:1254–1265.
37. Juker D, McGill S, Kropf P, et al. Quantitative intramuscular myoelectric activity of lumbar portions of psoas and the abdominal wall during a wide variety of tasks. *Med Sci Sports Exerc*. 1998;30:301–310.
38. McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil*. 1999;80(8):941–944.
39. Anderson D, Barthelemy L, Gmach R, et al. *Core strength testing: developing normative data for three clinical tests*. Doctor of Physical Therapy Research Papers. 2013 http://sophia.stkate.edu/dpt_papers/21.
40. Haff GG, Triplett NT. *Essentials of Strength Training and Conditioning*. 4th ed. Champaign IL: Human Kinetics; 2016.
41. Cowley P, Swensen T. Development and reliability of two core stability field tests. *JSCR*. 2008;22(2):619–624.
42. Cowley P, Fitzgerald S, Sottung K, et al. Age, weight, and the front abdominal power test as predictors of isokinetic trunk strength and work in young men and women. *JSCR*. 2009;23(3):915–925.
43. Butowicz CM, Ebaugh DD, Noehren B, et al. Validation of two clinical measures of core stability. *Int J Sports Phys Ther*. 2016;11(1):15–23.
44. Ekstrom RA, Donatelli RA, Carp KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sports Phys Ther*. 2007;37(12):754–755 [762].
45. Imai A, Kaneoka K, Okubo Y, et al. Trunk muscle activity during lumbar stabilization exercises on both a stable and unstable surface. *J Orthop Sports Phys Ther*. 2010;40(6):369–375.
46. Carlson B. Normal chest excursion. *Phys Ther*. 1973;53:10–14.
47. Leech JA, Ghezzo H, Stevens D, et al. Respiratory pressures and function in young adults. *Am Rev Respir Dis*. 1983;128:17.
48. Wade OL. Movements of the thoracic cage and diaphragm in respiration. *J Physiol (Lond)*. 1954;124:193–212.
49. Stone DJ, Keltz H. Effect of respiratory muscle dysfunction on pulmonary function. *Am Rev Respir Dis*. 1964;88:621–629.
50. Reid WD, Dechman G. Considerations when testing and training the respiratory muscles. *Phys Ther*. 1995;75:971–982.
51. American Thoracic Society/European Respiratory Society. ATS/ERS statement on respiratory

muscle testing. *Am J Respir Crit Care Med*. 2002;166(4):518–624.
52. DeTroyer A, Estenne M. Coordination between rib cage muscles and diaphragm during quiet breathing in humans. *J Appl Physiol*. 1984;57:899–906.
53. Le Niendre A, Mongodi S, Philippart F. Bouhemad B. Thoracic ultrasound: potential new tool for physiotherapists in respiratory management. A narrative review. *J Crit Care*. 2016;31:101–109.
54. Lerolle N, Guérot E, Dimassi S, et al. Ultrasonographic diagnostic criterion for severe diaphragmatic dysfunction after cardiac surgery. *Chest*. 2009;135:401–407.
55. Summerhill EM, El-Sameed YA, Glidden TJ, et al. Monitoring recovery from diaphragmatic paralysis with ultrasound. *Chest*. 2008;133:737–743.
56. Gosselink R, Wagenaar RC, Decramer M. The reliability of a commercially available threshold loading device in healthy subjects and in patients with chronic obstructive pulmonary disease. *Thorax*. 1996;51:601–605.
57. Gosselink R, Dal Corso S. Respiratory muscle training. Frownfelter D, Dean E. *Cardiovascular and Pulmonary Physical Therapy: Evidence to Practice*. 5th ed. Mosby Elsevier: St. Louis, MO; 2012:419–430.
58. Derrickson J, Ciesla N, Simpson N, et al. A comparison of two breathing exercise programs for patients with quadriplegia. *Phys Ther*. 1992;72:763–769.
59. Starr JA. Manual techniques of chest physical therapy and airway clearance techniques. Zadai CC. *Pulmonary Management in Physical Therapy*. Churchill-Livingstone: New York; 1992:142–148.
60. Konrad D. Hillegrass E. *Essentials of Cardiopulmonary Physical Therapy*. 4th ed. Elsevier: St. Louis, MO; 2017.
61. Evans JA, Whitelaw WA. The assessment of maximal respiratory mouth pressures in adults. *Respir Care*. 2009;54:1348.
62. Bach JR, Saporito LR. Criteria for extubation and tracheostomy tube removal for patients with ventilatory failure: a different approach to weaning. *Chest*. 1996;110:1566–1571.
63. Neumann P, Grimmer-Somers KA, Gill V, et al. Rater reliability of pelvic floor muscle strength. *Aust N Z Continence J*. 2007;13:9–14.
64. Retzky SS, Rogers RM. Urinary incontinence in women. *Ciba Clin Symp*. 1995;47(3):2–32.
65. Swift SE. The distribution of pelvic organ support in a population of female subjects seen for routine gynecologic health care. *Am J Obstet Gynecol*. 2000;183:277–285.
66. Hunskaar S, Burgio K, Diokno A, et al. Epidemiology and natural history of urinary incontinence (UI). Abrams P, Cardozo L, Khoury S, et al. *Incontinence*. Plymbridge Distributors Ltd: Plymouth, UK; 2002:165–201.
67. Kegel AH. Progressive resistance exercise in the functional restoration of the perineal muscles. *Am J Obstet Gynecol*. 1948;56:238–249.
68. Lewis RW, Fugl-Meyer KS, Corona G, et al. Definitions/epidemiology/risk factors for sexual dysfunction. *J Sex Med*. 2010;7(4 Pt 2):1598–1607.
69. Knoepp LR, Shippey SH, Chen CC, et al. Sexual complaints, pelvic floor symptoms, and sexual distress in women over forty. *J Sex Med*. 2010;7:3675–3682.
70. Laumann EO, Paik A, Rosen RC. Sexual dysfunction in the United States: prevalence and predictors. *JAMA*. 1999;281:537-544. *Erratum in JAMA*. 1999;281(13):1174.
71. Dennerstein L, Randolph J, Taffe J, et al. Hormones, mood, sexuality, and the menopausal transition. *Fertil Steril*. 2002;77(suppl 4):S42–S48.
72. Dietz HP, Schierlitz L. Pelvic floor trauma in childbirth—myth or reality? *Aust N Z J Obstet Gynaecol*. 2005;45:3–11.
73. Plevnik S. *A new method for testing and strengthening of pelvic floor muscles [abstract]*. [In:] Proceeding of the 15th Annual Meeting of the International Continence Society. 1985 [London, UK; September].
74. Bø K, Sherburn M. Evaluation of female pelvic-floor muscle function and strength. *Phys Ther*. 2005;85:269–282.
75. Dietz H, Jarvis S, Vancaillie T. The assessment of levator muscle strength: a validation of three ultrasound techniques. *Int Urogynecol J Pelvic Floor Dysfunct*. 2002;13:156–159.
76. Bø K, Lilleås F, Talseth T, et al. Dynamic MRI of pelvic floor muscles in an upright sitting position. *Neurourol Urodyn*. 2001;20:167–174.
77. Laycock J. Clinical evaluation of the pelvic floor. Schussler B, Laycock J, Norton P, et al. *Pelvic Floor Re-education*. Springer-Verlag: London, UK; 1994:42–48.

78. Ferreira CH, Barbosa PB, de Oliveira Souza F, et al. Inter-rater reliability study of the modified Oxford Grading Scale and the Peritron manometer. *Physiotherapy*. 2011;97(2):132–138.
79. Hundley AF, Wu JM, Visco AG. A comparison of perineometer to brink score for assessment of pelvic floor muscle strength. *Am J Obstet Gynecol*. 2005;192:1583–1591.