

# The Back Squat: A Proposed Assessment of Functional Deficits and Technical Factors That Limit Performance

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## ABSTRACT

FUNDAMENTAL MOVEMENT COMPETENCY IS ESSENTIAL FOR PHYSICAL ACTIVITY PARTICIPATION AND FOR REDUCING INJURY RISK, WHICH ARE BOTH KEY ELEMENTS OF HEALTH PROMOTION. THE SQUAT MOVEMENT PATTERN IS ARGUABLY ONE OF THE MOST CRITICAL FUNDAMENTAL MOVEMENTS NECESSARY TO IMPROVE SPORT PERFORMANCE, TO REDUCE INJURY RISK, AND TO SUPPORT LIFELONG PHYSICAL ACTIVITY. BASED ON CURRENT EVIDENCE, THIS FIRST (1 OF 2) REPORT DECONSTRUCTS THE TECHNICAL PERFORMANCE OF THE BACK SQUAT AND PRESENTS A NOVEL DYNAMIC SCREENING

TOOL THAT INCORPORATES IDENTIFICATION TECHNIQUES FOR KNOWN FUNCTIONAL DEFICITS. THE FOLLOW-UP REPORT WILL OUTLINE TARGETED CORRECTIVE METHODOLOGY FOR EACH OF THESE FUNCTIONAL DEFICITS.

## INTRODUCTION

Fundamental movement skills are essential for participation in physical activity and mitigating the risk of injury, which are both key elements of health throughout life (25). Young people, for example, without adequate motor skill proficiency in the early developmental years may experience a heightened risk of sports-related injuries during adolescence and into adulthood (11,32,34). Thus, development of competence in fundamental

movements must be viewed as an essential component of preparatory training before vigorous physical activity and organized, competitive sport. Some fundamental movement patterns include running, throwing, lunging, and squatting (25). These fundamental movements have direct biomechanical and neuromuscular implications to successful performance with dynamic tasks inherent to many popular sports and physical activities enjoyed by youth and young adults (24,35). Movement competency as a principle extends through into the later adult years, for whom the joy of independent living

## KEY WORDS:

functional deficit identification; injury prevention; physical activity; screening tool; sport performance; squat

rests on their ability to maintain strength and mobility to avoid injuries such as falling (44).

The squat movement pattern is required for essential activities of daily living, such as sitting, lifting, and most sporting activities. It is also a staple exercise in training regimens designed to enhance performance and to build injury resilience (30–32). Despite variations on how squat technique is instructed and executed to address specific performance goals, nearly all squat variations comprise a standard, basic, and fundamental blueprint that underlies the biomechanical technique that will support progressive physical attribute improvements and decrease the risk of training induced injuries (3). In addition, the unloaded back squat (herein referred to as “back squat”) has been proposed for use as a screening tool to identify biomechanical deficits that may hinder optimal movement patterns compromising performance and injury resilience (20). In particular, the back squat can be used to assess an individual for neuromuscular control, strength, stability, and mobility within the kinetic chain (1,4,10,31,39,42).

The purpose of this commentary is to deconstruct the technical performance of the back squat and the related evidence, as both a foundation training exercise and dynamic screening tool. Specifically, we aim to describe common functional deficits during back squat performance known to increase

injury risk during training and dynamic sport. Identified deficits and injury mechanisms will be formalized together with anatomical variations that influence squat kinematics and kinetics. In the follow-up manuscript, we aim to present detailed targeted training exercises and techniques to correct biomechanical deficits (part II), which is vital to improve the technical skill and competence of the back squat (22). Achieving this competency is the foundation for younger individuals to partake in training progressions that enhance performance and injury resilience, and for older adults to live independently and safely (25).

### THE BACK SQUAT

The back squat is widely regarded as one of the most effective exercises used to enhance athletic performance because it necessitates the coordinated interaction of numerous muscle groups and strengthens the prime movers needed to support explosive athletic movements, such as jumping, running, and lifting (7). Furthermore, back squat proficiency supports derivative squat movements that translate to many everyday tasks, such as lifting and carrying heavy objects, which relates this exercise to improve quality of life (43). The squat has also become more commonly used in clinical settings to strengthen lower-body musculature (especially posterior chain strength and recruitment patterns) with little to no harm on connective tissue after joint-related injury (7,43).

Specifically, closed kinetic chain exercise is commonly used throughout the rehabilitation process to avoid excessive strain being placed on the anterior cruciate ligament, making the squat a favorable exercise for rehabilitation (7,17,37,43). It is highly recommended that an individual is first able to demonstrate proficiency during body weight back squat performance before advancing to more intense variations and derivatives of squatting, such as externally loaded squats and plyometric training.

The back squat exercise is most often prescribed with an individual starting in a standing position with the feet flat on the floor, the knees and hips in a neutral, extended anatomical position, and the spine in an upright position with preservation of its natural curves (7,43,45). The squat movement begins with the descent phase as the hips, knees, and ankles flex. A common instruction is to descend until the top of the thigh is at least parallel with ground and the hip joint is at least level with or slightly below the knee joint (Figure 1) (3,43). Ascent is achieved primarily through triple extension of the hips, knees, and ankles, continuing until the subject has returned to the original extended, starting position (3). The posterior torso muscles, particularly the erector spinae, are recruited by isometric muscle action to support an upright posture throughout the entire squat movement. Furthermore,

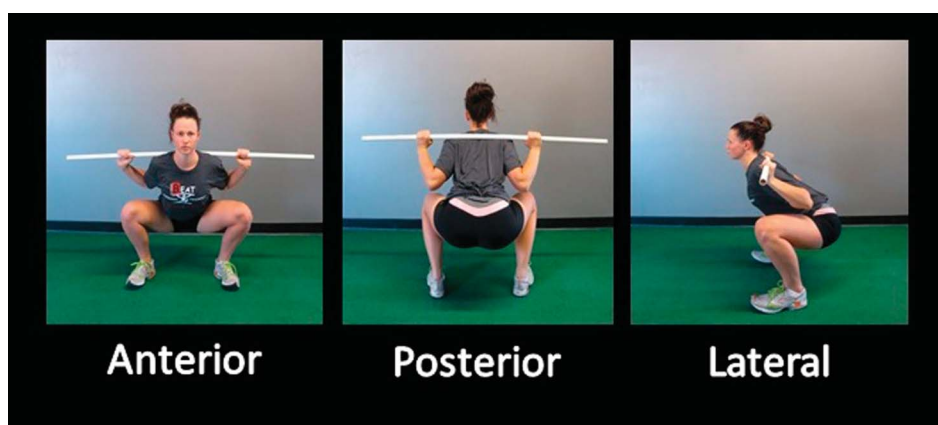


Figure 1. Recommended squat depth presented from the anterior, posterior, and lateral perspective.

the posterior torso muscles are assisted by the anterior and lateral abdominal muscles to further stiffen the torso by creating tension for the abdominal wall.

Before the initiation of the descent phase, it is recommended for the athlete to inhale approximately 80% of maximal inhalation and hold their breath to increase intra-abdominal pressure to enhance stability of the vertebral column (i.e., Valsalva maneuver) (note: this amount of air may change with the load magnitude). This technique prepares the spine, which is a flexible rod, to bear a compressive load. The Valsalva maneuver also establishes “proximal stiffness” that enables more power development in the shoulders and hips, enhancing limb force output and velocity.

## IDENTIFICATION OF BIOMECHANICAL DEFICITS DURING THE BACK SQUAT

The basic squat movement is considered by many professionals to be a valuable primary physical training exercise because it is a single compound maneuver that is highly sensitive to highlight biomechanical deficits (12,13,33,42). Deficits identified during the back squat that can impair performance can be categorized as inefficient motor unit coordination or recruitment (neuromuscular), muscle weakness, strength asymmetry or joint instability (strength), and/or joint immobility or muscle tightness (mobility) (43). It is important to identify the biomechanical and anatomical limitation(s) that most egregiously underlies aberrant movements to ameliorate identified deficit(s) through an appropriate and effective targeted corrective strategy (part 2) (12,13,33,42). With the use of the proposed Back Squat Assessment (BSA) screening tool (Table 1), a practitioner may be able to more efficiently and objectively identify underlying deficit(s) responsible for functional limitations during back squat performance and to guide corrective targeted exercise progressions.

## THE BACK SQUAT ASSESSMENT

The authors of this commentary developed the proposed BSA (Table 1) screening tool to assist practitioners

in systematically identifying specific functional deficits to guide targeted corrective intervention. The authors propose that observed movement impairments or deficits through guidance of the BSA suggest that an individual may have an elevated injury risk and suboptimal physical performance (4). Moreover, the BSA is a versatile tool that provides an alternative means to expensive and sophisticated laboratory evaluation to identify biomechanical deficits.

Ten criteria to be scored are provided in the BSA, which are subcategorized into 3 comprehensive domains: upper body, lower body, and movement mechanics (Table 1). The 3 domains are integrated into the BSA to improve the systematic assessment of the back squat. It may be challenging to score all 10 criteria of the BSA at once during real-time observation. The categorization of similar criteria into 3 domains offers a practitioner a strategic guide to focus attention on scoring 1 domain at a time. The upper body domain emphasizes the stability and posture of the head, neck, and torso. The lower body domain assesses the joint positions of the hips, knees, and ankles during the squat. Finally, the criteria in the movement mechanics domain assess the timing, coordination, and recruitment patterns of the back squat. All 10 criteria from the 3 domains can be individually assessed for neuromuscular, strength, and mobility deficits as prompted on the BSA score sheet (Table 1).

To initiate the assessment, the athlete should be asked to perform 10 continuous back squat repetitions. The BSA will necessitate analysis from the anterior, posterior, and lateral perspectives and therefore it may be advantageous for practitioners to record video of the athlete performing the BSA from all 3 perspectives to facilitate a more accurate and thorough deficit screening.

The criteria are written in the affirmative and each should be critiqued and scored independently of each other. If a single criterion is not met to standard, an observed deficit should be marked. Next, the practitioner should indicate if they believe the deficiency is related to

a neuromuscular, strength, or mobility limitation by circling the respective category to guide targeted exercise corrections (part 2). If unsure, mark all categories that are suspect to improper technique. A perfect score of 0 indicates 10 flawless squat repetitions. A deficit should be marked if the individual fails to demonstrate the desired technique of a criterion to perfection during 2 or more repetitions. Additional space for comments is provided on the score sheet and may be useful for a practitioner to make supplementary notes to guide their targeted corrective intervention. An athlete should be referred to a licensed health care professional if they indicate pain or discomfort during any phase of the squat assessment.

## STANDARDIZED ASSESSMENT

### BACK SQUAT INSTRUCTION

For the purpose of maximizing the consistency of the assessment, the BSA should be administered with arm position, stance, and verbal instruction in standardized fashion.


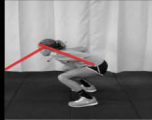




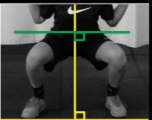
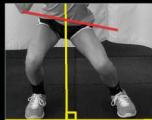


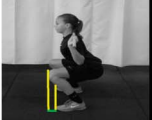






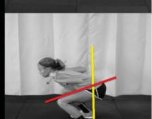


### ARM POSITION INSTRUCTIONS

A lightweight cylindrical dowel (wooden, metal, or plastic; approximately 1¼" × 36" long) is recommended to be used to set-up the athlete in a desired upper torso position while controlling for arm position. Furthermore, the use of a dowel in the back squat position can serve to prepare an athlete for future back squat progressions that incorporate external resistance. In addition, the dowel-aided position likely facilitates engagement of the scapular stabilizers essential to upper body performance in the back squat.

Athletes are to be instructed to grip the dowel with a pronated grip slightly greater than shoulder width apart and assume a back squat set-up, with the dowel resting comfortably on their contracted upper back musculature. Specifically, the dowel should be positioned across the posterior deltoids just below C7 of the cervical spine. Forearms should be held parallel to the torso, and wrists should be kept

Table 1

## The Back Squat Assessment

	Criteria	Description	Correct	Incorrect	Deficit	Type	Comments
<b>Domain 1: Upper Body</b>							
①	<b>Head Position:</b>	Line of neck is perpendicular to the ground and gaze is aimed forward.			<input type="checkbox"/>	Neuromuscular Strength Mobility	
②	<b>Thoracic Position:</b>	Chest is held upward and shoulder blades are retracted.			<input type="checkbox"/>	Neuromuscular Strength Mobility	
③	<b>Trunk Position:</b>	Trunk is parallel to tibia, while maintaining slightly lordotic lumbar spine.			<input type="checkbox"/>	Neuromuscular Strength Mobility	
<b>Domain 2: Lower Body</b>							
④	<b>Hip Position:</b>	Line of hips is parallel to ground in frontal plane throughout squat.			<input type="checkbox"/>	Neuromuscular Strength Mobility	
⑤	<b>Frontal Knee Position:</b>	Lateral aspect of knee does not cross medial malleolus for either leg.			<input type="checkbox"/>	Neuromuscular Strength Mobility	
⑥	<b>Tibial Progression Angle:</b>	Knees do not excessively pass the front of the foot. Tibias are parallel to an upright torso.			<input type="checkbox"/>	Neuromuscular Strength Mobility	
⑦	<b>Foot Position:</b>	Entire foot remains in contact with the ground.			<input type="checkbox"/>	Neuromuscular Strength Mobility	
<b>Domain 3: Movement Mechanics</b>							
⑧	<b>Descent:</b>	Utilizes hip-hinge strategy at a controlled, constant speed throughout descent. Torso remains upright.			<input type="checkbox"/>	Neuromuscular Strength Mobility	
⑨	<b>Depth:</b>	At apex of depth, the tops of thighs are at least parallel to the ground.			<input type="checkbox"/>	Neuromuscular Strength Mobility	
⑩	<b>Ascent:</b>	Shoulders and hips rise at the same, constant speed to return to start position. Descent : Ascent timing ratio is at least 2:1.			<input type="checkbox"/>	Neuromuscular Strength Mobility	
<b>Total:</b>					<input type="checkbox"/>		

Total:



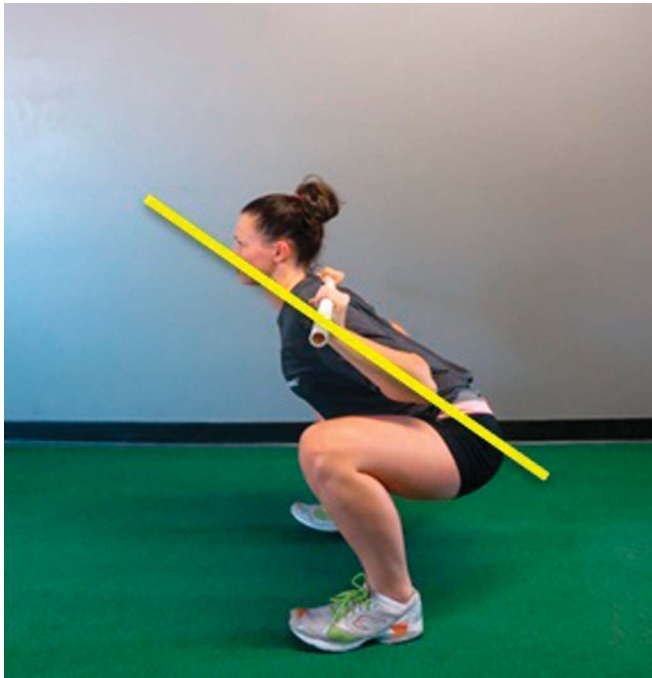


Figure 2. Forearm position with dowel.

straight and not flexed throughout the movement (Figure 2). The person should be taught to “bend the bar” (pull the bar into trapezius) because this facilitates the back extensors, shoulder retractors, and latissimus—all of which stiffen the torso, adding to injury resilience and performance capabilities. If a dowel is not available, the athlete can be instructed to mimic holding a dowel with their hands open palmed under their ears while retracting their scapulae.

## STANCE INSTRUCTIONS

The athlete should be instructed to assume an initial stance position with heels approximately shoulder width apart and toes pointing forward or slightly outward by no more than 10°. Extreme stance widths and foot positions (tibial rotation) are not recommended when initially instructing the squat and may limit the utility of the BSA. Escamilla et al. (8) assessed the kinematics and kinetics of the squat at 3 varying widths (a wide stance, shoulder width, and narrow stance). A wide stance may increase patellofemoral and tibiofemoral compressive

forces in the knee joint by up to 15% during descent (7,9,43). However, an excessively narrow stance may increase forward knee translation and therefore heighten anterior shear forces (7,43). Therefore, a moderate stance width is encouraged for this standardized assessment.

Regarding foot position, it is important for the knee to function in its intended role as a hinge joint. During goal-specific squat exercise, moderate variations of foot placement may be warranted; however, it is recommended that athletes do not exceed 30° of internal ankle rotation or 80° of external rotation to maximize stability and promote normal patella tracking (21,43). Still, extreme tibial rotation in a closed chain movement may potentially lead to increased stress on the static knee structures and should be avoided for most squat variations.

## SCRIPT FOR INSTRUCTING THE ASSESSMENT

Once the athlete is properly set-up with the dowel and stance in the

appropriate position, verbal instructions for the BSA can be delivered. The authors recommend using the following standardized verbal script to promote inter-rater reliability for the BSA:

“Please stand upright with feet shoulder width apart. Squat down until the top of your thighs are at least parallel to the ground, and then return to the initial starting position. Perform 10 continuous repetitions at a consistent, moderate pace or until you are instructed to stop.”

## Set-up Summary

**Arm position:** A dowel is held in back squat position with forearms parallel to torso and upper back musculature contracted.

**Stance:** Feet are placed with heels shoulder width apart and toes forward or slightly outward.

**Script:** “Please stand upright with feet shoulder width apart. Squat down until you believe that the top of your thighs are parallel to the ground, and then return to the initial starting position. Perform 10 continuous repetitions at a consistent, moderate pace, or until you are instructed to stop.”

## DOMAIN 1: UPPER BODY

Domain 1 focuses on the musculoskeletal components of the upper body that are responsible for maintaining postural control during the squat.

## HEAD POSITION

As a precursor to sports performance training for youth, the neck should demonstrate adequate physiological ranges of motion of flexion, extension, rotation, and side bending in the absence of pain or discomfort. Simple neck rolls and head tilts can be used as an assessment for neck mobility. If an athlete indicates pain or discomfort when attempting to achieve physiological ranges of neck motion, it is advised to abstain from training and refer the individual to a licensed health care professional.

Maintaining the head and neck in neutral alignment (to slight extension) with the torso is an important facet to provide the athlete with a strong, balanced set-up and point of reference throughout the squat (6). Incorrect positioning of the head and neck may negatively cascade into improper spinal positioning and tracking throughout the range of the movement (6). In theory, the spine, although comprised many vertebral links, acts as a single entity. A change in alignment in 1 section of the spine may influence compensation in another section. Furthermore, poor body alignment as a result of incorrect head position may predispose an athlete to injury during more intense squat exercises (6,15).

Practitioners should be aware that head position and gaze direction (focal point) are related but independent. Gaze can be directed by keeping fixed eyes and moving the head, or by moving the eyes independently of a fixed head (6). Both head position and gaze have been shown to influence spinal kinetics and kinematics (43).

#### *Desired technique. Head position*

The athlete's head should be maintained in a neutral position (to slight extension)

in relation to the spine (Figure 3). The neck should be held in line to the plane of the torso.

#### **Gaze**

Point of focus for gaze is instructed to be either straight ahead or slightly upward (Figure 3) (6). It is hypothesized that athletes may have a tendency to move in the direction of their gaze and therefore a downward gaze is not recommended during ascent. A slightly upward gaze during ascent may help guide an athlete to lead with their head and chest rather than raising their hips first when beginning the concentric portion of the squat. In addition, a slight upward gaze throughout the movement may help prevent excessive forward trunk flexion.

*Screening.* Observe the athlete's head position from the lateral perspectives. From the lateral perspective, chin position and anterior/posterior head tilt can be observed. From the anterior perspective, assess the athlete's direction of gaze.

#### *Common deficits. Head position*

Most athletes will be able to achieve proper head position during the initial

set-up phase for the squat. Muscle strain or injury to the cervical vertebrae during exercise may result from improper neck position. Therefore, movement of head too far forward or backward and movement of head laterally to either side should be explicitly avoided. Excessive tilting of the head backward into a position of extreme cervical hyperextension can be dangerous during the squat, particularly when heavy resistance is integrated (2). Excessive cervical hyperextension may be a compensatory movement for a lack of thoracic extension. Excessive cervical flexion may also result in a greater tendency to extend the lumbar spine, which can increase lumbar compression forces (Figure 4). Conversely, if head position is directed too far downward into cervical hyperflexion, a significant increase in hip and trunk flexion may result as a compensation mechanism, which is not considered an optimal movement strategy for the back squat and other sport activities such as tackling in football (6). From the posterior perspective, ensure that the athlete's neck position is perpendicular to the line of the shoulder and there is no lateral head tilt in either direction. If an athlete is unable to



Figure 3. Correct head position.

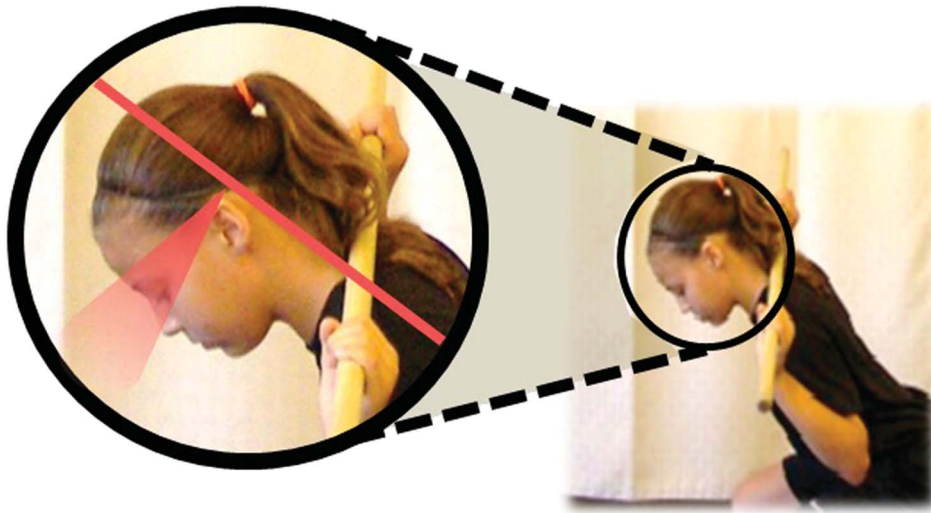


Figure 4. Incorrect head position.

maintain his or her head and neck in a neutral position throughout the entire squat, the deficit may either be due to neck muscle weakness (i.e., trapezius muscles) or inadequate postural awareness.

### Gaze

Gaze can either be directed too high or too low. A downward gaze has been shown to increase hip flexion and potentially trunk flexion in comparison with an upward gaze (Figure 4). This position may place increased torque on the vertebral column (2,6,43). However, it is important to disassociate gaze from head position. Although gaze can be slightly upward, the head position should not deviate from neutral. Most errors concerning gaze direction can be corrected by verbal and visual cueing.

### Head Position Deficits Summary

**Neuromuscular:** Unsatisfactory head and neck position awareness for maintaining neutral head position throughout squat. Poor disassociation of gaze from head position, which may encourage deviation from neutral head position.

**Strength/stability:** Insufficient isometric strength of neck and upper back

musculature to maintain head in neutral alignment throughout the entire squat.

**Mobility:** Insufficient physiological range of motion for head and neck in all 3 planes.

### THORACIC POSITION

The athlete must be able to demonstrate adequate postural stability and control of the upper torso as optimal squat technique favors a rigid spine that does not concede to any planar motion. Stable, upright posture should be sustained throughout the movement as a more vertically positioned upper spine, contracted upper back musculature, and chest-up position reduces shear forces on the intervertebral disks.

**Desired technique.** It is preferred that the thoracic spine is slightly extended and held rigid (3). The chest is directed outward and upward to bring the torso angle to a more vertical position (3), and this position should be maintained throughout the entire squat movement. The chest can be positioned upward independently of trunk angle (criterion 3). The scapulae should be held retracted and depressed while the glenohumeral joint maintains a position of relative

external rotation, which pushes out the chest and keeps the upper torso erect (Figure 5). As a result, the shoulders will assume a slightly rolled back position. The athlete's forearms should be held parallel to their spine and the shoulders should be retracted and not rolled forward. This position allows for major supporting back muscles (i.e., latissimus dorsi, erector spinae, trapezius, rhomboids) to contribute maximally to spinal stability (28). In addition, a tight upper back with retracted scapulae can help provide the athlete with a favorable position to rest the dowel in the most secure and comfortable manner during back squats (28).

**Screening.** Observation of the upper spine and chest position can be made primarily from the lateral perspective.

**Common deficits.** A thoracic position in which the chest is not held upward and is positioned toward the ground signifies a deficit in the back squat technique (Figure 6). In addition, any flexion or excessive extension of the thoracic spine, either constantly or sporadically, may be indicative of biomechanical compensatory strategies (3). Another deficit of the upper torso is that the scapulae are relaxed



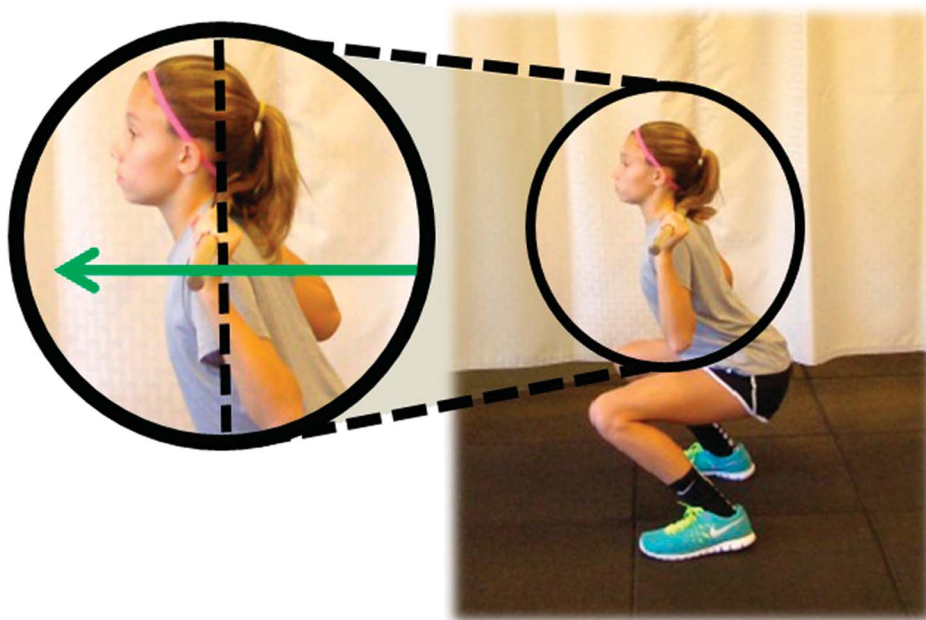


Figure 5. Correct thoracic position.

or abducted (i.e., “protracted scapula”) and visually evidenced as having the shoulders rolled forward. If verbal or physical cueing to instruct the athlete to position their chest up or retract their shoulders does not gain desired technique, then

the athlete may lack adequate torso strength, such as the thoracic paraspinal musculature or parascapular musculature, or insufficient neuromuscular coordination to perform the exercise to standard. A propensity for forward rolled shoulders

during the back squat may also be due to lifestyle-induced postural weaknesses (i.e., upper crossed syndrome, which results from consistently internally rotated shoulders leading to excessively shortened or tight pectorals).

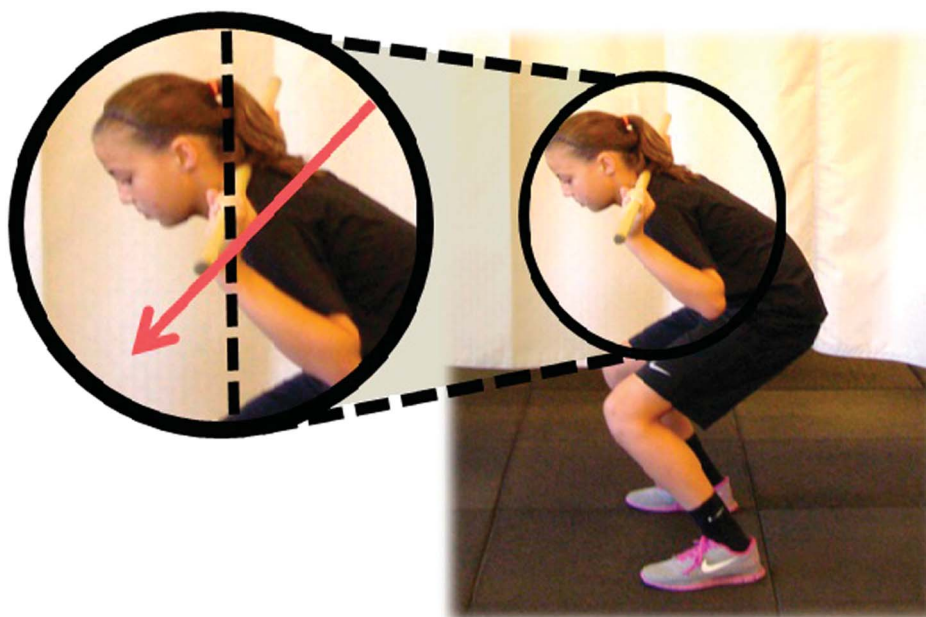


Figure 6. Incorrect thoracic position.



# The Back Squat

## Thoracic Position Deficits Summary

**Neuromuscular:** Chest down or lack of scapular retraction during squat. Difficulty dissociating the thoracic position from the lower trunk position.

**Strength/stability:** Inability to maintain chest-up position, which may be due to weakness of erector spinae, trapezius, and rhomboids.

**Mobility:** Excessive tightness in chest, potentially from upper crossed syndrome, which hinders ability to open chest and retract scapula.

## TRUNK POSITION

Trunk stability and control are derived from the lower back musculature, obliques, lumbar paraspinals, quadratus lumborum, and abdominals. The body's core is a critical modulator of lower extremity alignments and loads during dynamic tasks such as squatting (33). The stabilizers of the trunk and hip can preactivate to counterbalance unwanted trunk motion and regulate lower extremity postures during the squat (33). Decreased core stability and muscular synergism of the trunk and hip stabilizers negatively affect performance in power activities and may increase the incidence of injury due to lack of control of the center of mass

(14,33). The squat exercise can help instill mechanics that improve trunk stability during dynamic tasks.

Stability during the squat is enhanced with muscular stiffness of all muscles around the lumbar spine. Failure to stiffen the lower back musculature, combined with poor lifting mechanics, increases the potential to overload spine and back tissues to the point of injury, especially when repeated over time (27,29). A more upright lumbar posture increases load onto lower extremity levers, which may reduce low back stress. Some may dismiss the need to preserve the neutral curvature of the lumbar spine when squatting. However, this is problematic as the spine loses its ability to bear load when the neutral curve is lost, which prevents eventual progression of the squat with load while maintaining a reduced injury risk. In summary, the individual must demonstrate the ability to maintain a stiffened torso with a neutral, lordotic lumbar position as a safe and optimal squat strategy.

*Desired technique.* The lumbar vertebrae are maintained in a neutral alignment throughout the entire squat

movement (28). This entails maintaining a slight lordotic curve in the lumbar region while holding the abdomen upward and rigid to promote stability (Figure 7). The trunk should remain as upright as possible during the squat to minimize lumbar shear forces associated with forward lean (28). Furthermore, the trunk should remain stable throughout the squat without any observation of wavering or displacement. A general guideline to ensure adequate trunk posture is to necessitate that the line of the trunk is maintained parallel to the line of the tibias from the lateral perspective. However, this guideline also necessitates proper foot and knee position.

*Screening.* Observation of the lumbar spine and trunk angle can be made primarily from the lateral perspective.

*Common deficits.* It is suboptimal for the trunk musculature to be in a relaxed state and allow the trunk to collapse downward into excessive trunk flexion (Figure 8). The muscles form a guide wire system that prepares the flexible spinal column to bear load and they must be activated. Common culprits for increased

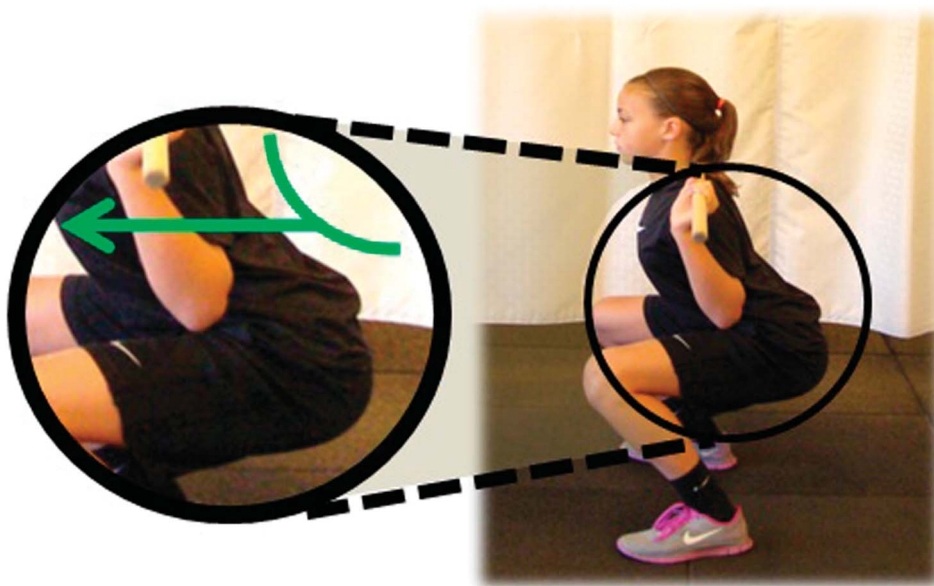


Figure 7. Correct trunk position.

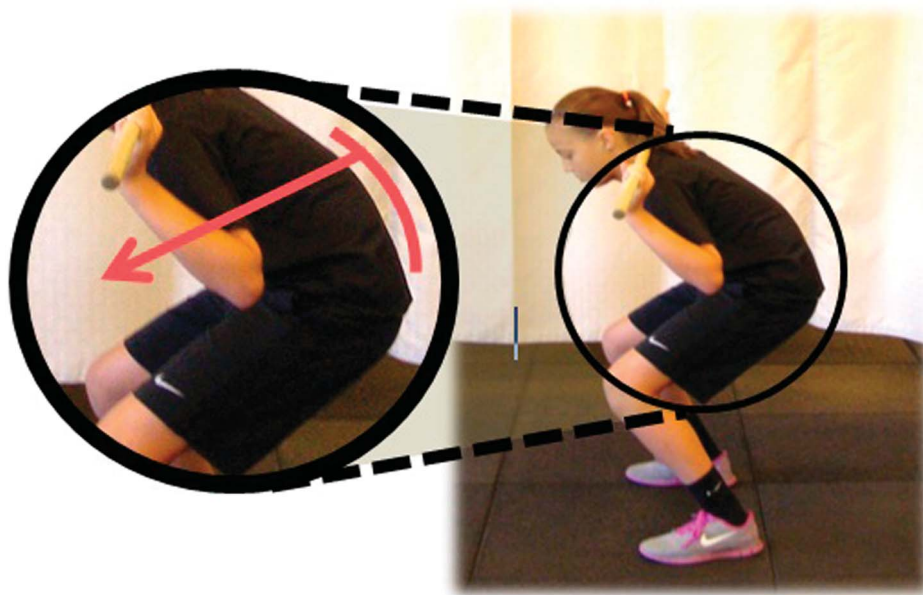


Figure 8. Incorrect torso position.

trunk flexion during the squat are weakness of the thoracic and lumbar paraspinals (erector spinae), weakness of the parascapular musculature to maintain retracted and depressed scapulae, and reduced tension in the thoracolumbar fascia through the integration of the posterior chain and back musculature. In addition, restricted translation of the knees during the squat may also increase anterior forward lean of the trunk (16). A trunk that is unsteady and moves out of an upright position during the squat may be indicative of general core weakness.

The squat requires sufficient spinal mobility to assume and maintain slight lordotic posture. Otherwise, an individual may tend to take forward posture and place excessive pressure to the lower back, especially if their head is tilted forward as well. Insufficient hip mobility may also negatively affect the ability to preserve a lordotic spine, which may be due to genetics, previous injury, or tight connective tissues. If the athlete flexes at the spine before  $120^\circ$  of hip flexion when squatting, they may have restriction in the posterior fibers of the iliotibial band or lack of lumbar control.

Observation of a rounded spine, or kyphosis, due to relaxed back musculature and spinal flexion indicates a deficit for the BSA (Figure 8). If an athlete does not stiffen the back musculature to support the spine positioned in a neutral, slightly lordotic position, increased and potentially harmful compressive and shear forces of the lumbar spine may result during more intense squat variations (28). The risk of disc herniation is increased during heavy resistance squatting, with the spine in a flexed position as a result of excessive stress placed on intervertebral discs (26,43).

The most critical component to correcting a deficit with the lumbar spine and abdomen is identification of the mechanism driving the failure to desired technique. Due to the complex nature of this area, one or a combination of problems could exist. Having the athlete execute a squat to at least parallel with only a dowel as the external resistance will allow the coach to gauge when and if the athlete presents a movement pattern including excessive anterior or posterior pelvic tilt. If the athlete is unable to maintain a slight lordotic curve in the lumbar spine and keep the trunk

angle parallel with the tibial angles, then specific corrective actions should be taken (part 2).

#### Trunk Position Deficits Summary

**Neuromuscular:** Excessive trunk flexion and/or rounding (kyphosis) of the spine during the back squat.

**Strength/stability:** Inadequate core strength to maintain torso parallel to tibias and lack of lower back tightness to generate spinal stability. Deficit may be due to trunk extensor weakness and hip extensor weakness.

**Mobility:** Excessive hip flexors (iliopsoas) and trunk flexors (abdominals) tightness and/or lack of lumbar spinal mobility.

## DOMAIN 2: LOWER BODY

Domain 2 encompasses the musculoskeletal components and positions of the 3 major joints of the lower extremities during the back squat.

### HIP POSITION

The hip joint is a ball-and-socket joint capable of motion in all 3 planes. It is responsible for providing a pathway of the transmission of forces between the lower extremities and the pelvis during

## The Back Squat

squatting (43). Evidence suggests that maintaining a neutral pelvic tilt during the squat increases activity of the erector spinae and oblique muscles, helping to ensure optimal muscular support for the spine while handling loads, thereby reducing the risk for low back injury (5).

The gluteus maximus is the largest muscle of the hip. During the squat movement, the gluteus maximus extends the femur and stabilizes the pelvis (43). The squat can be an effective training exercise to promote the development of gluteal strength, which is important for athletes as these muscles are prime movers in dynamic sports-related movements, such as running and jumping (33). Furthermore, without proper recruitment of the gluteal muscles, other muscle groups, such as the quadriceps, must bear the load of the squat, which is suboptimal and may increase the risk of muscle imbalance and injury. The hamstrings are an assemblage of 3 muscles, including the biceps femoris, semitendinosus, and semimembranosus, which originate on the pelvis and insert at the top of the bones of the lower leg (43). Because the hamstrings cross both the hips and

the knees, they moderate movements at both joints (33). During descent, the hamstrings can assist the gluteal muscles by controlling flexion at the hips (43). In the ascent phase of the squat, the distal hamstrings contract to extend the hips. The hip abductors, muscles of the hip and outer thigh, including the gluteus medius and the gluteus minimus, stabilize the femurs during the squat. They prevent the knees and hips from rotating inward during descent. Moreover, internal rotation of the femurs may be caused by tight hip adductors, muscles on the inner thigh (1).

**Desired technique.** The athlete maintains square, stable hips with minimal mediolateral movement during the squat (Figure 9). Squat depth should be determined based on the position of the hips (2). The position of the femurs should remain symmetrical throughout the entire exercise (2). It is optimal if the line of the hips from the frontal perspective is parallel to the ground. The athlete is also encouraged to maintain the pelvis in normal/neutral tilt, particularly during the descent phase of the movement. This is particularly important in the final part of the descent.

**Screening.** A deficit can be identified by observing the athlete leaning, dropping, or twisting to one side from the anterior or posterior perspective.

**Common deficits.** Observation of mediolateral rotation or unilateral dropping, which results in asymmetrical hip movement, constitutes a deficit of the hip position. This deficit is evident if the line of the hips is not parallel to the ground in the frontal plane (Figure 10). Hip asymmetries may be due to weaknesses, muscle imbalances in the gluteal complex, or joint asymmetries involving the hip capsule and labrum. It has been reported that an athlete lacking hip mobility will demonstrate a compensatory movement pattern of increased trunk flexion (3). Hip position deficits can be noted through observations of one hip positioned lower than the other in the frontal plane or observation of the dowel dropping down to one side during the squat.

### Hip Position Deficits Summary

**Neuromuscular:** Hips are asymmetrical in frontal plane during the back squat.

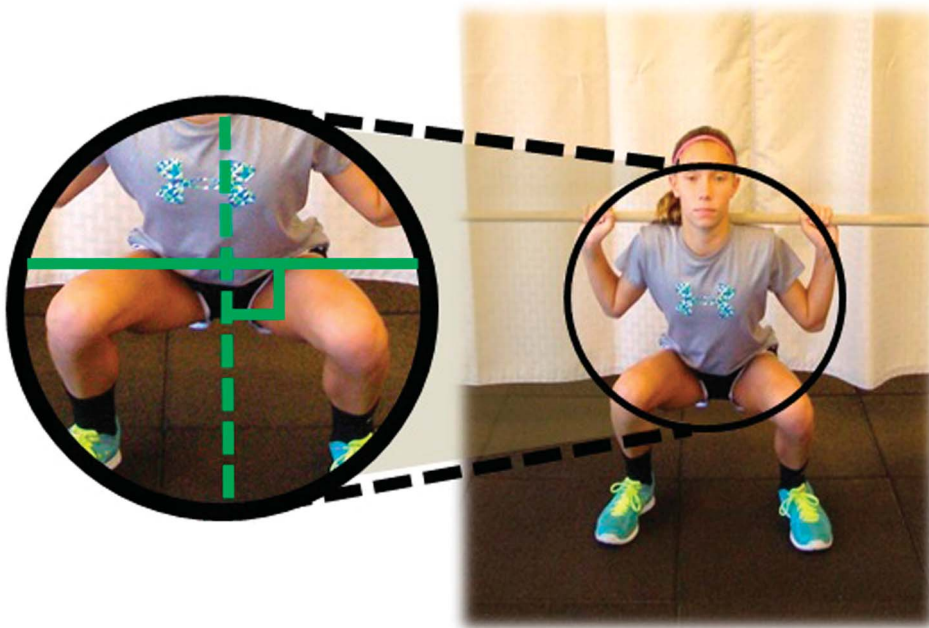


Figure 9. Correct hip position.



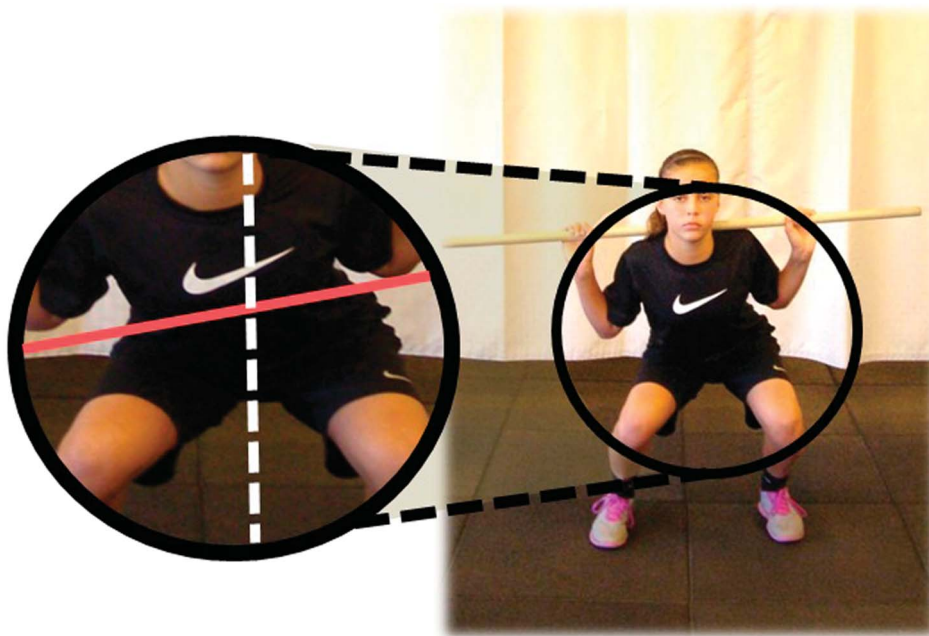


Figure 10. Incorrect hip position.

**Strength/stability:** Lack of strength or stability of hip musculature or asymmetrical strength of hips.

**Mobility:** Lack of hip flexor range of motion.

#### **FRONTAL PLANE KNEE ALIGNMENT**

Internal knee force response to external loads is primarily generated by the quadriceps, hamstrings, and gastrocnemius (43). Tibiofemoral compressive forces help resist anteroposterior shear forces and translation (43). Tibiofemoral and patellofemoral compression has been shown to increase with increasing knee angle as a protective function at the knee by initiating a co-contraction between the quadriceps and hamstrings (43). Therefore, closed kinetic chain exercises such as the back squat exercise may support appropriate rehabilitation exercise after ligament reconstruction surgery (16). Although shear forces tend to increase with increasing knee angles, forces on the cruciate ligaments of the knee decrease at high flexion angles (43). Thus, there is no known evidence to support the contention that squat depth below parallel increases the potential for injury to the cruciate and collateral

ligaments and menisci in the knee during deep flexion (43). Training with the squat exercise may enhance passive and dynamic knee stability in deep knee flexion positions by active muscular protection of the passive structures during sport movements (7,8,19,39).

**Desired technique.** The knees should track over the toes throughout the squat motion visually evident as a neutral frontal plane knee position throughout the movement (i.e., the foot is positioned to create a perfect in-line hinge with knee motion). There should be an absence of knee displacement both medially and laterally. The lateral aspect of the knee should not cross the vertical plane of the medial malleolus when assessing for medial displacement (Figure 11). Although the goal position is to have the tibia in vertical alignment perpendicular to the floor with error toward lateral knee positions, the medial aspect of the knee should also not cross the vertical plane of the lateral malleolus.

**Screening.** Observe excessive mediolateral movement of the knees from the anterior perspective (i.e., knock-kneed position).

**Common deficits.** Excessive mediolateral movement of the knees signals a functional deficit. Valgus or varus frontal plane movement can be attributed to poor neuromuscular control and lack of function or strength of the lower extremity musculature, especially the posterior chain complex. Knee valgus (medial or knock-kneed movement) during the squat may be influenced by decreased hip abductor and hip external rotation strength, increased hip adductor activity, and restricted ankle dorsiflexion (4). Observed valgus during the squat may be due to a suboptimal active neuromuscular pattern of the athlete. Active valgus, which is a position of hip adduction and knee abduction as a result of muscular contraction, is often the underlying cause for observed dynamic valgus during the back squat. From an observational standpoint, medial knee motion is a much more common deficit relative to knee varus (outward movement of the knee). However, knee varus can occur and is sometimes a compensatory strategy used by athletes with flat feet. A neutral knee alignment is desired and feedback should be given to correct varus or valgus positioning during the movement.

## The Back Squat

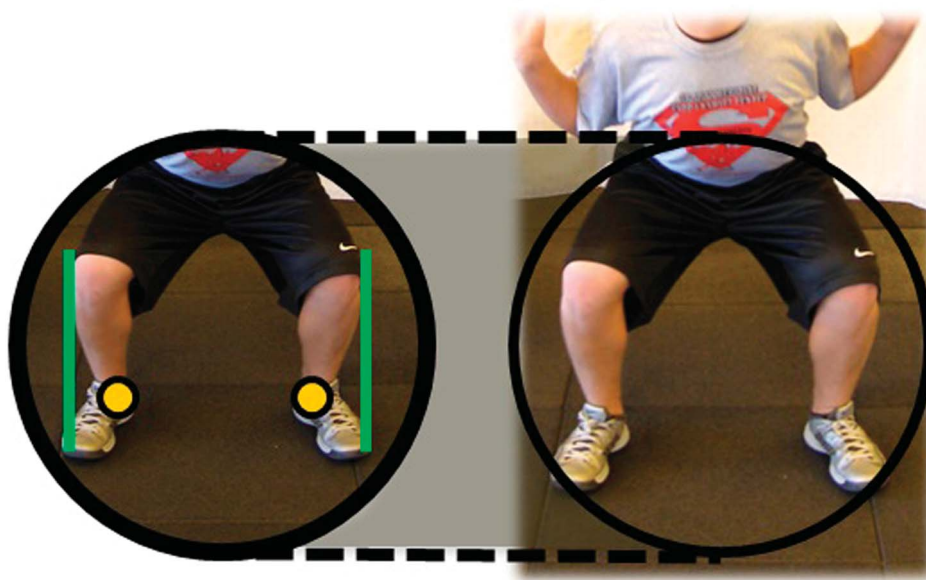


Figure 11. Correct frontal knee position.

Knee valgus can be identified by observation of the medial aspect of either knee passing the medial malleolus from the anterior perspective during any phase of the squat (Figure 12).

### Frontal Knee Position Deficits Summary

**Neuromuscular:** Active valgus during the back squat; increased hip adductor activation without adequate posterior chain control and recruitment may lead to knee valgus.

**Strength/stability:** Posterior chain weakness which leads to passive valgus during squat motion.

**Mobility:** Hip immobility that restricts knees from avoiding valgus position during squat.

### TIBIAL TRANSLATION ANGLE

As a general rule, increased anterior tibial translation increases torque about the knee joint (16). Although this observation has led some practitioners

to caution against allowing the knees to travel past the toes, there is no known evidence that a defined point exists whereby injury risk exceeds the potential benefits during the squat exercise. Moreover, a conscious effort to restrict forward translation has been shown to increase forward trunk lean, resulting in significantly greater forces at the hip and spine that place these joints at greater risk of injury (16,23). Thus, on the proviso that feet remain firmly

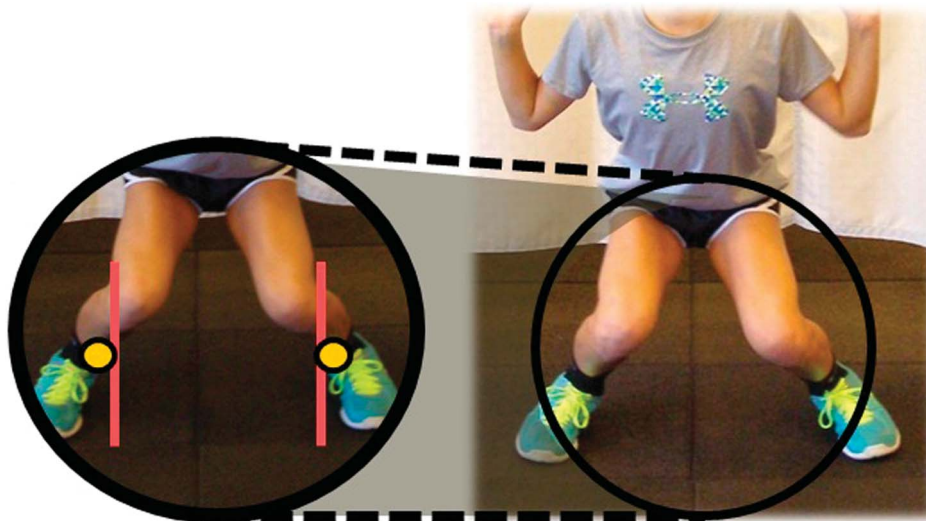


Figure 12. Incorrect knee position.

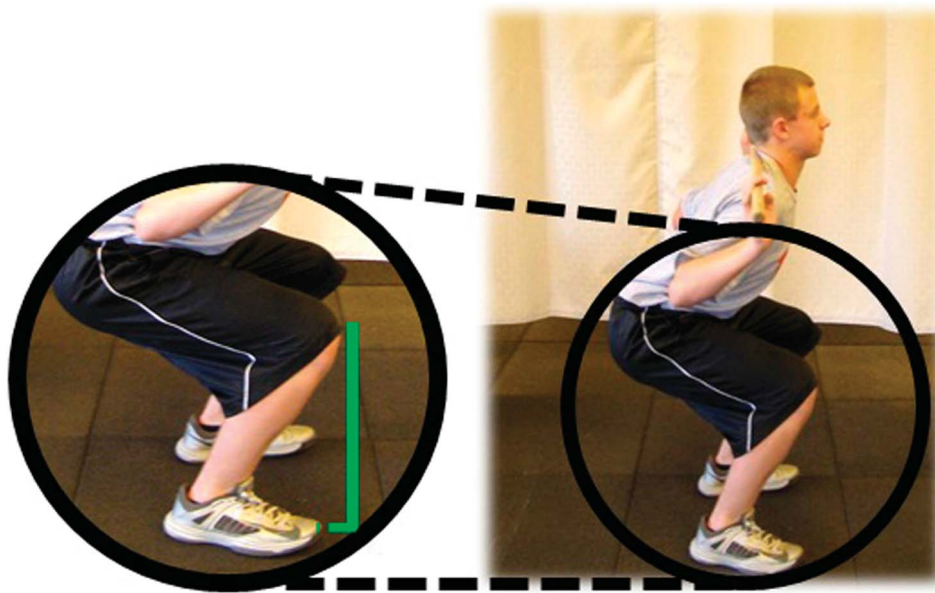


Figure 13. Correct tibial translation.

fixed on the floor, anterior tibial translation angle should be unrestricted with the focus on initiating the squat descent by breaking the hips back (16). Adequate tibial translation angle is able to be achieved by normal foot and ankle capsular mobility, soft-tissue flexibility, and proper joint mechanics.

*Desired technique.* Although the general goal should be to maintain

a positive shin angle, this objective should be accomplished by proper hip joint kinematics (16,45). The knees therefore should move freely in accordance with hip range-of-motion. The extent of anterior tibial translation will vary between individuals depending on anthropometrics, in particular the torso and leg length ratio. As a general guideline, the athlete should attempt to match tibia

angle in parallel with an upright trunk while keeping their heels on the ground (Figure 13).

*Screening.* Observe tibial translation from the lateral perspective.

*Common deficits.* Athletes may either demonstrate excessive translation or excessive restriction of the tibial progression angle (Figure 14).



Figure 14. Incorrect tibial translation.



# The Back Squat

Excessive anterior translation of the knees over the toes is purported to increase shearing forces on the knee and greater knee extensor torque (30). Overly restricted tibial translation during the squat increases anterior lean of the torso, which accompanies increases in hip torque and lumbar shear forces (16). The optimal position of tibial progression angle may support active muscular recruitment of the lower extremity while avoiding unwanted stresses on the passive structures. Often weak gluteal muscles influence the body to use a strategy to alternatively place load on the knees increasing tibia progression rather than on the rear (33). Excessive tibial progression angle can also be exacerbated by weakness in the calf and soleus, weak hamstrings, or quadriceps dominance. Restricted motion of the gastrocnemius and soleus muscle complex by the Achilles tendon, talocrural joint restrictions at

the posterior ankle, restrictions in hip mobility, and deficits in foot mobility may also hinder proper tibial progression angle. An evaluation by a licensed health care provider may be necessary if a good stretching and mobility routine for the posterior calf musculature does not improve proper performance.

## Tibial Translation Angle Deficits Summary

**Neuromuscular:** Knee translates excessively over toes during the back squat, even with heel on the ground.

**Strength/stability:** Lack of strength of posterior chain, particularly the gluteals, to keep load on the rear. Excessive tibial progression angle can be a result of weakness in calf and soleus, weak hamstrings, or quadriceps dominance.

**Mobility:** Inadequate mobility of knee in sagittal plane from lack of mobility of the soleus and gastrocnemius.

## FOOT POSITION

Adequate ankle mobility supports a balanced and controlled squat movement. However, foot and ankle position can be influenced by proximal forces as well, which may need to be ruled out to determine the cause of the movement deficit. The ability of the athlete to maintain a flat and stable foot position during the back squat necessitates adequate ankle dorsiflexion (3).

*Desired technique.* Ensure the athlete's feet are stable and planted firmly on the ground. The athlete should keep their entire foot on the ground throughout the entire squat motion (Figure 15). The suggested center of pressure in the foot moves from the mid-foot during initial stance toward the heel and lateral foot ("L" foot loading position) during the descent phase of the squat, and bodyweight is distributed through the lateral foot and heel

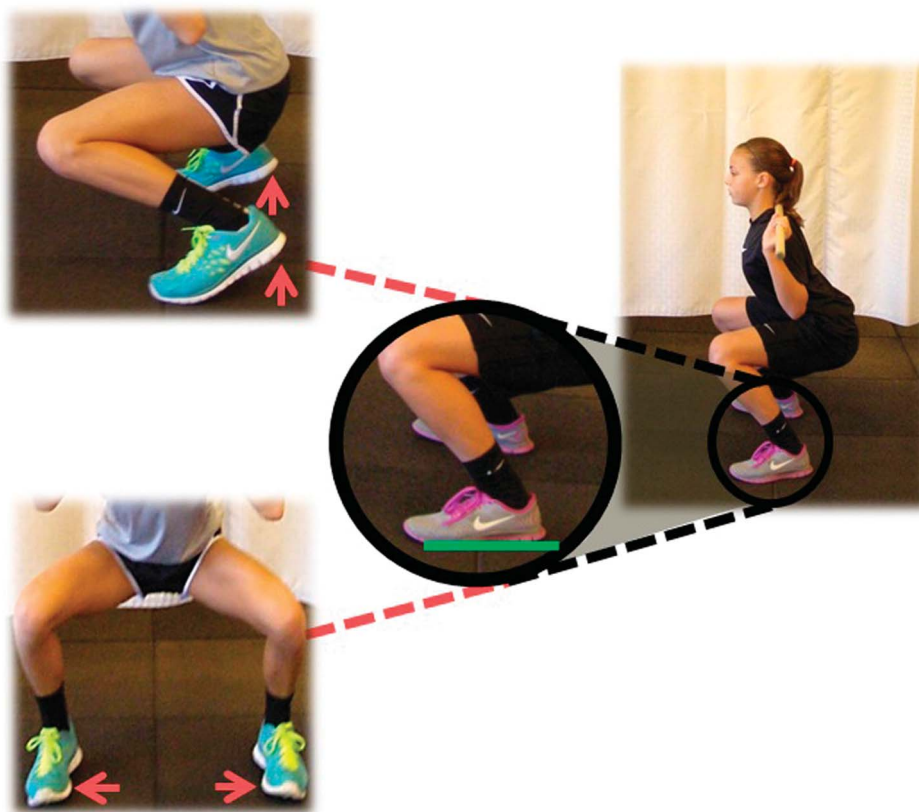


Figure 15. Foot position.

until the athlete completes the ascent (3). As the athlete descends, body weight should be emphasized through the heel and lateral foot while keeping the toes on the ground to ensure balance. Placing more body weight toward the back of the foot facilitates desired hip motion strategies during the entire squat phase. In addition, placing more body weight toward the lateral aspect of the foot encourages improved recruitment of the gluteal muscles.

**Screening.** Observe foot position from the lateral, anterior, and posterior perspectives to assess for any aspect of the foot coming off of the ground.

**Common deficits.** Observations of pronation or supination of the feet and the rolling of the feet inward or outward are suboptimal movement strategies. Lifting heels or toes off of the ground at any time is suboptimal during the back squat (Figure 15). Allowing the heels to rise off the ground has been observed to create compensatory torques about the ankles, knees, hips, and lumbar spine (3). With heels raised off of the ground, the athlete has a smaller surface area and base of support, which may reduce the athlete's ability to perform a balanced and controlled squat.

Ankle inversion or eversion during the squat is also indicative of a biomechanical deficit. Although pressure should be emphasized toward the lateral side of the foot, the medial side should not come off of the ground to promote balance and stability. The calcaneus should not appear everted relative to the lower leg (20). Stiffness in the ankle joint from poor dorsiflexion may cause the foot and the knee joints to compensate (3). These compensations may have a negative impact to foot and knee stability that is needed for correct squat mechanics.

Furthermore, weakness in the ankle musculature has been implicated in faulty movement patterns during the squat. A lack of strength in the medial

gastrocnemius, tibialis anterior, and/or tibialis posterior decreases the athlete's ability to control knee valgus and foot pronation motions and may contribute to excessive medial knee displacement and dynamic valgus (1). Although increasing ankle mobility, and in many cases hip mobility, is the desired endpoint for this deficit, some athletes may benefit initially from the use of a heel block to aid in creating a stable platform and assist in pushing through the heels.

#### Foot Position Deficits Summary

**Neuromuscular:** Foot comes off of ground during squat not due to strength or mobility limitations.

**Strength/stability:** Lack of or asymmetrical ankle strength and/or poor stabilization of ankle and foot. Foot rolls onto either side during squat.

**Mobility:** Lack of dorsiflexion mobility if heels come up off ground due to restricted Achilles tendon and/or tight soleus and gastrocnemius.

### DOMAIN 3: MOVEMENT MECHANICS

Domain 3 analyzes the kinematics of the squat and discusses the limitations of functional deficits on proper movement mechanics. Triple extension (extension of ankle, knee, and hip) and flexion movement patterns are inherent to sports-associated movements, such as jumping and landing mechanics.

#### DESCENT

After achieving a proper set-up, the athlete is instructed to initiate the squat movement with the descent phase. Throughout the descent, the athlete should maintain full control of their velocity and descending position. The athlete should descend by flexing the hip, knees, and ankles in a fluid, coordinated movement as the body is lowered in a controlled manner.

**Desired technique.** The descent is initiated with the breaking of the hips ("hip hinging") while

maintaining a rigid, upright trunk. Breaking the hips at the initiation of the squat movement migrates the load to the posterior chain, which is a more safe strategy for the knees and lumbar vertebrae (33). The athlete should reach back as if sitting in a chair that is slightly too far away as they descend to the desired depth. The goal should be for the athlete to keep their rear as far away from their ankles while maintaining an upright torso throughout the squat. The vertical distance between the athlete's shoulders and hips should remain constant throughout the entire descent. Body weight should be transferred to and supported by the athlete's posterior chain musculature, particularly the hamstrings and gluteals, and not placed anteriorly on their knees (Figure 16). The descent of the squat should move back in a vector that remains at a constant downward angle. The athlete should move at a controlled tempo with no less than 2:1 (descent: ascent) up to a 4:1 ratio in regard to velocity of the eccentric movement compared with the concentric ascent phase.

**Screening.** Observe descent technique and tempo from the lateral perspective.

**Common deficits.** Observation of excessively rapid or unsteady movement of the body during descent should be considered a deficit. In addition, incorrect descent mechanics may also be noted if the athlete does not maintain constant speed and control during the entire eccentric phase, which is particularly common in novice lifters (31). Furthermore, a common mechanical deficit is for athletes to place load down on the anterior aspect of the knees rather than back on the hips during descent (Figure 17). Typically, this incorrect strategy can be observed with, but not limited to, excessive tibial progression angle (criteria 6) and/or heels coming off of the ground (criteria 7). This incorrect descent strategy may place excessive shear

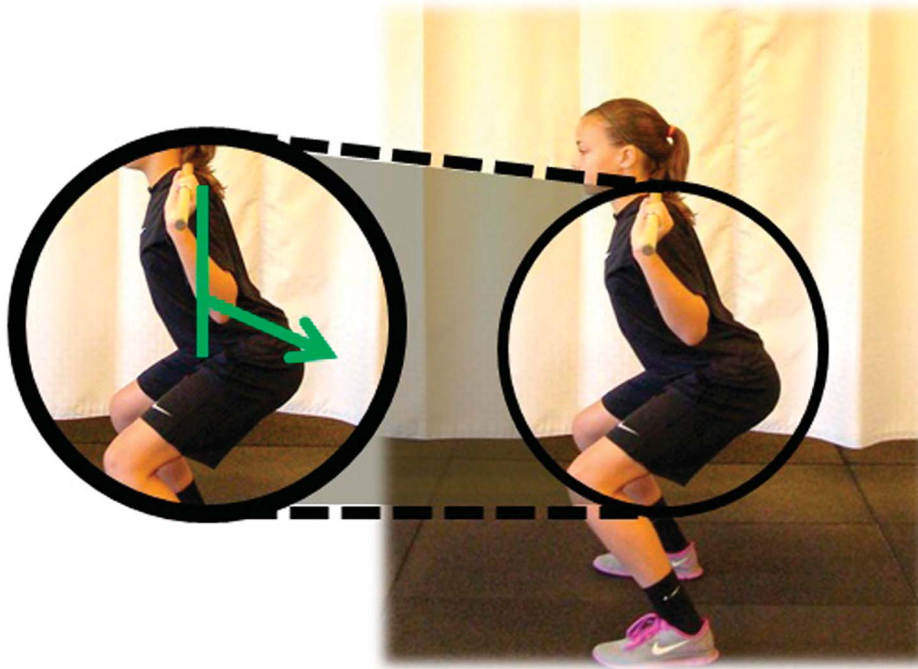


Figure 16. Correct descent mechanics.

forces on the anterior knee and decreases recruitment of the posterior chain musculature. Athletes with insufficient posterior chain (i.e., hamstrings, gluteals) strength may be more likely to lose descent control

toward the later phases of the movement and may favor a knee loading strategy. In addition, more intense squat variations, such as high velocity eccentric movements, can be dangerous if the muscles are forced to

stretch too greatly in a short amount of time. Practicing and mastering controlled descent strategies support the development of strategies that can mitigate risk of training induced injuries.

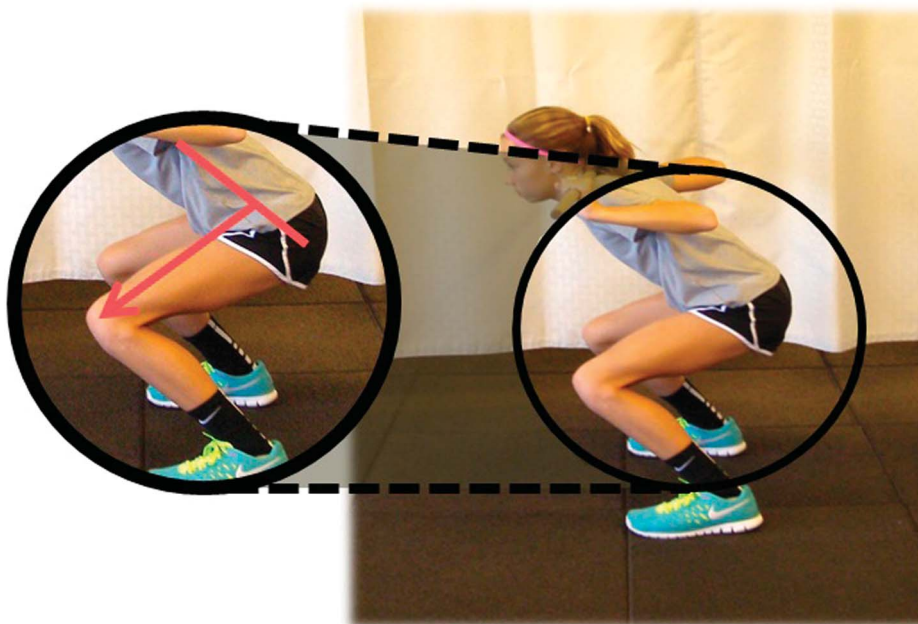


Figure 17. Incorrect descent mechanics.



### Descent Deficits Summary

**Neuromuscular:** “Knee-loading” strategy instead of “hip-hinge” strategy as seen with excessive trunk flexion, excessive tibial progression angle, and/or heels coming off of the ground.

**Strength/stability:** Lack of lower limb eccentric strength control, evidenced by an overall lack of control of the tempo of the descent. The athlete seems to “drop” into the apex of the descent. Descent timing is not a 2:1 ratio in relation to ascent.

**Mobility:** Lack of lower limb mobility, leading to a forward trunk lean.

### DEPTH

Squatting to appropriate depth is a critical component in deriving the full benefit of the activity. Without squatting to the proper depth, the hamstrings and gluteus muscular complex may not be adequately challenged. Specifically, training at shallower knee flexion can influence quadriceps-dominant sport skill performance that can limit performance and increase injury risk (19,39). Likewise, training at deeper depths will help benefit motor control positions that are common to sport. The skill and strength gains achieved during deep knee and hip flexion positions may help reduce quadriceps dominance strategies that are purported to increase injury risk (18,37,38). As noted previously, evidence that indicates squatting below parallel increased the potential for injury to the cruciate and collateral ligaments or menisci in the knee during extreme flexion does not exist (43). The squat exercise may enhance active knee stability if performed correctly and may reduce sport injury risk to the passive structures of the knee (7,8,39).

**Desired technique.** The athlete achieves full depth with the tops of the thighs at least parallel to the ground without any disjointed deviations noted at the knee, ankle, or hips. At the proper depth, the femurs are slightly past parallel to the ground, hips are back, tibias are positioned

vertical, and feet are entirely on the ground (Figure 18). Furthermore, this position allows the squatter to achieve desired depth by not falling victim to soft tissue restrictions such as the thighs blocking the abdomen, thus hindering the ability to achieve an appropriate depth (2).

**Screening.** Observe the apex of depth position from the lateral perspective.

**Common deficits.** The most common deficit of depth during the back squat is from the athlete squatting too shallow (Figure 19). Although squatting excessively past parallel can occur, it is not often detrimental to the athlete. If contraindicated based on existing pathology, excessive squat depth can be easily corrected with cueing and feedback. The athlete may lack isometric strength of the posterior chain to maintain body-weight support at the apex of depth. Furthermore, tightness in the posterior chain musculature and hip adductors may further limit the ability for an athlete to achieve appropriate depth.

### Depth Deficits Summary

**Neuromuscular:** Athlete does not achieve depth of thighs at least parallel to the ground.

**Strength/stability:** Athlete lacks posterior chain isometric strength to maintain deep hold.

**Mobility:** Difficulty achieving depth due to tightness in posterior chain and hip adductors.

### ASCENT

The ascent of the squat should follow the same path as the descent in the reverse direction. The primary driver of the ascent should be the hips, and weight should be kept off the heels and lateral sides of the feet. The torso of the athlete should remain fairly static throughout the ascent as the ankles, knees, and hips extend into the original position.

**Desired technique.** The torso should remain upright during the entire ascent phase. The shoulders and hips should rise at the same pace and the difference in vertical height of the shoulders and hips should remain constant (Figure 20). The back is to be kept in a rigid, tight position with stiffened muscles and with the lumbar spine in a neutral to slightly extended position. The athlete should use a hip drive strategy as the primary driver for the ascent. The athlete should only exhale once the ascent has been completed.

**Screening.** Observe ascent technique and tempo from the lateral perspective.

**Common deficits.** Common faults in early stages of learning the back squat (i.e., early training age) are for the hips to rise faster than the shoulders, which would increase trunk flexion (Figure 21). If the hips rise too quickly, the vertical distance between the hips and shoulders will decrease during the early ascent phase (Figure 21). Irrespective of the load, the movement pattern represents an incorrect back squat that can be a dangerous strategy to the lower back during squatting with progressive external resistance. In addition, relative to the downward descent, a large deviation in the movement pattern used during upward ascent is also considered a deficient technique.

Knee position during ascent may also greatly influence mechanics. If the knees are too far back in relation to the trunk, the athlete is forced to lean forward with their torso to stay in balance. If the knees are too far forward, an acute shift of postural balance occurs, requiring the athlete to shift their body weight onto their toes instead of their heels. This strategy influences an inefficient hip drive out of the transition phase of the movement. Typically, mechanical deficits of ascent are due to suboptimal motor recruitment patterns that can be improved through neuromuscular training and corrective cueing feedback.

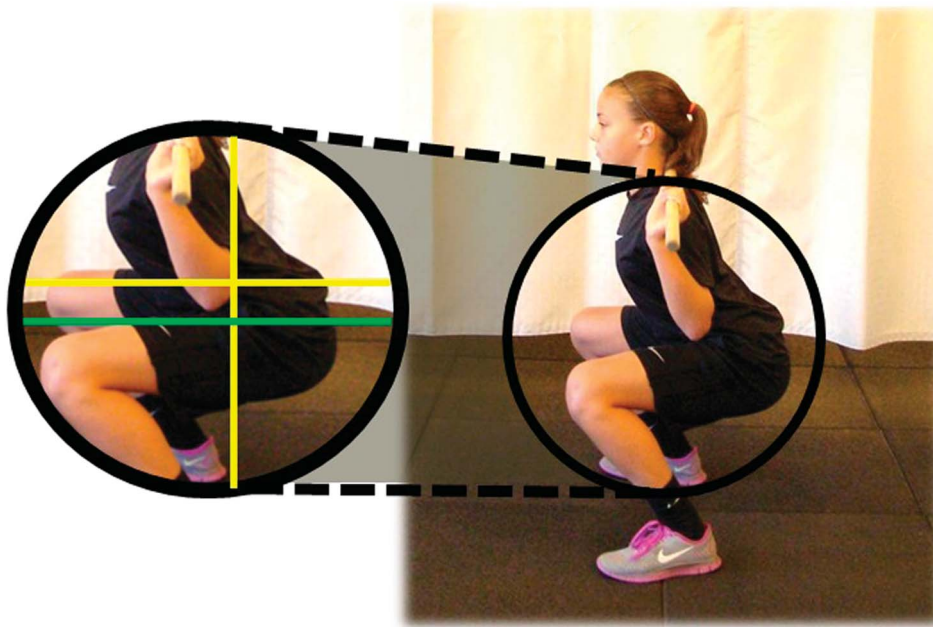


Figure 18. Parallel squat depth.

## Ascent Deficits Summary

Neuromuscular: Hips rise too quickly in relation to shoulders during ascent. The vertical distance between the hips and shoulders does not remain constant.

Strength/stability: Posterior chain and hip extension concentric muscle action weakness.

Mobility: Lack of thoracic spine and hip flexor mobility.

## ADDITIONAL CONSIDERATIONS FOR THE SQUAT

### ANATOMICAL VARIATION

The proposed form and technique in the 10 BSA criteria are meant to be

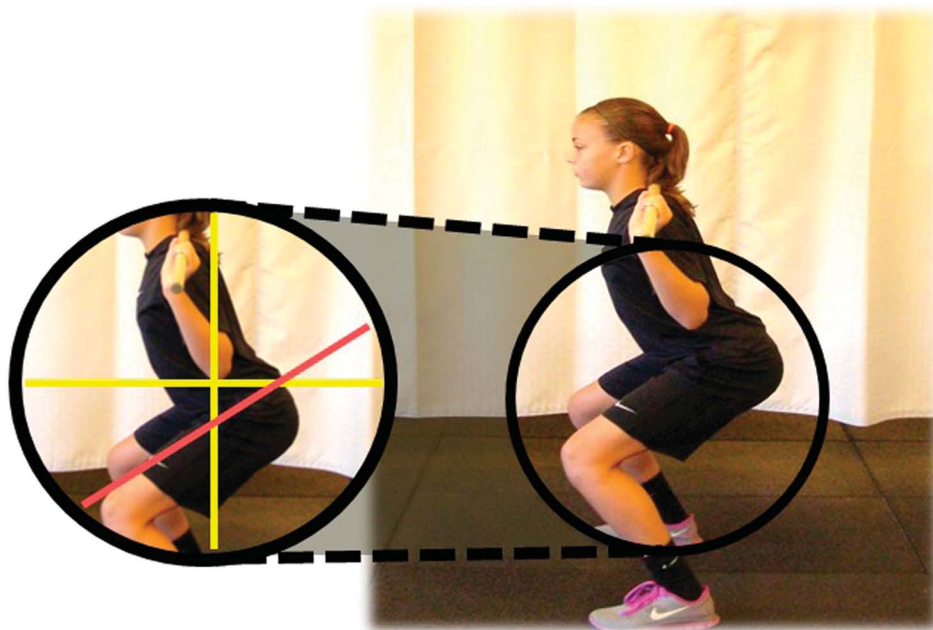


Figure 19. Incorrect depth.

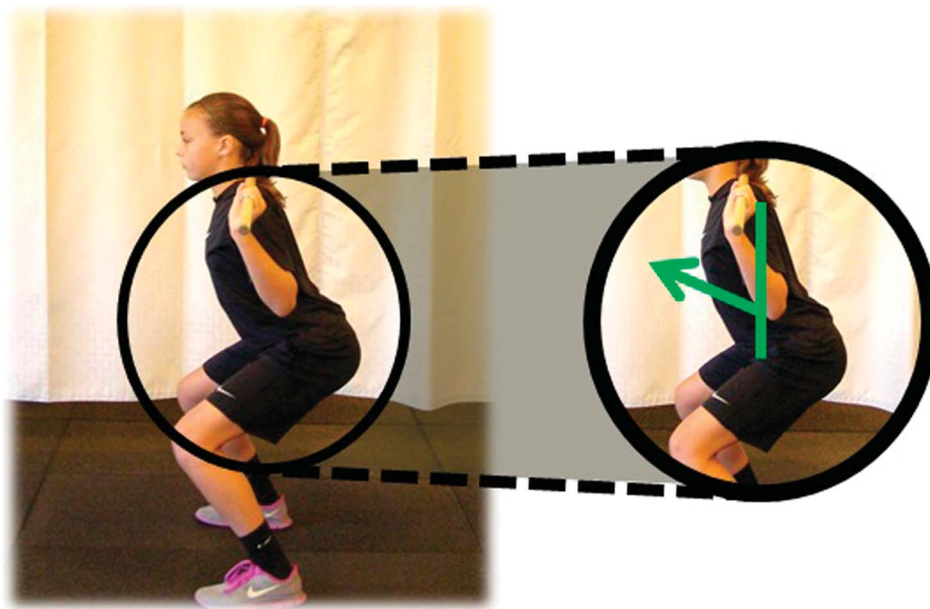


Figure 20. Correct ascent mechanics.

set as an ideal standard for all athletes. However, it is understood that anatomical variation may predispose some athletes to have disadvantages in achieving these desired positions and mechanics. The factors of anatomical variation most influencing the squat are the

anatomy of the hip, together with the ratio of torso length to leg length. The shape of the hip joint determines the type and incidence of specific hip pathology and squat depth. While a deeper hip joint increases standing stability to the joint, it prevents the

femur from flexing into a deep squat without pinching the hip joint labrum and joint capsule. This bony restriction nullifies any attempt to stretch or mobilize the joint to perform the deep squat. Assessment of this feature begins with the individual kneeling on their hands

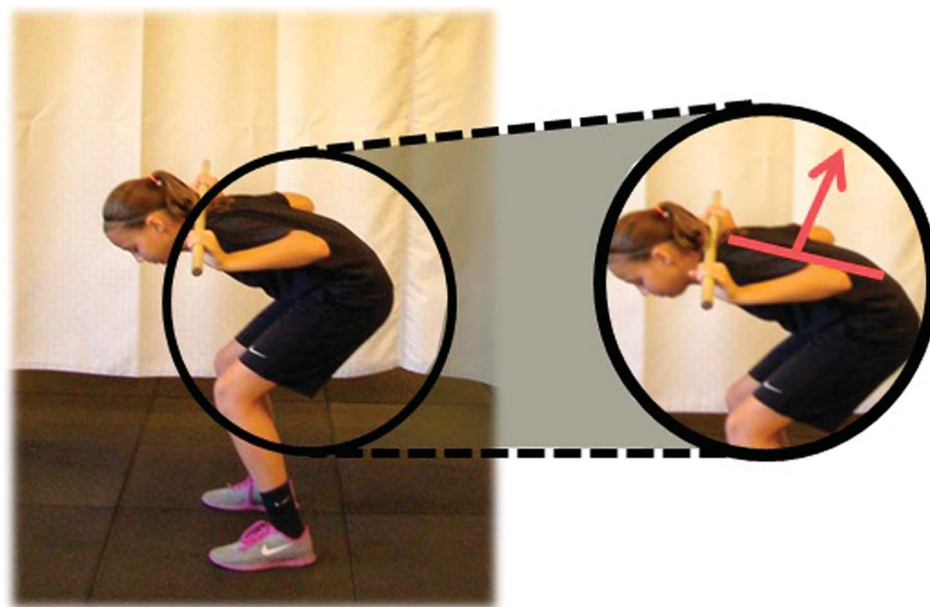


Figure 21. Incorrect ascent mechanics.



and knees. The knees are initially placed together. Then the pelvis is rocked back toward the heels. The test stops when the neutral spine curvature begins to flex. Then the knees are spread apart a few inches and the “pelvic rock” test is repeated and the depth of the kneeling squat is noted. In this way, the ability to deep squat without compromising the back curvature is quantified, together with identifying the optimal width for the feet and knees when squatting.

Other suggestions for squat safety involve knee loading and whether the knee may be allowed to travel ahead of the toe. This also is a function of the leg length and torso length ratio. A 7-foot tall basketball center usually has longer legs than torso, such that the knees travel way ahead of the toes. The length of the femur creates a long lever and a high patellar tendon load. Generally, these athletes squat with their hips back to balance the knee and hip loads. In contrast, an individual with a longer torso to leg length ratio squats with more emphasis on knee motion, and the shin remains parallel to the torso, equally sharing hip and knee loads.

## **INTEGRATING THE SQUAT INTO ATHLETIC PREPARATION TRAINING**

Participation in organized sports does not safeguard youth from developing poor or inefficient movement patterns. Athletes who do not demonstrate proper mechanics may use compensatory movement strategies that can hinder their athletic performance and heighten their risk of sports-related injury (4,24). In the absence of pressures or cueing during activity to modify these inefficient movements, athletes will continue to master and imprint these suboptimal strategies that will likely propagate into movements used in sport competition. Non-athletes with poor squat mechanics will more likely suffer the same fate of eventual pain and suboptimal performance. The back squat offers an opportunity to teach and instill a correct functional movement pattern providing the foundation upon which to build

strength and mobility abilities. For example, it is suggested that the squat reflects lower extremity movement patterns often required for success in explosive sport techniques that are likely to expose the lower extremity to high joint loads (4). Improved strategies to help young athletes absorb, redirect, and create explosive squat-related movements can help enhance performance outcomes and reduce injury risk factors (36,39). On a more broad level, preservation of the competency to squat can prolong independent living in older adults.

Proficiency with the back squat is a prudent prerequisite to heavy resistance squat training, especially for young athletes with a low training age (35). An individual should be able to display perfect back squat technique consistently before moving on to more advanced squatting variations, including depth jump plyometric training. In addition, by developing proper squat mechanics before using external resistance, an athlete can minimize the potential to instill improper compensatory strategies and decrease the risk of training-related injuries (34). It is outside the scope of this review to discuss the many useful technical variations of the squat movement (i.e., sumo squat, front squat). However, it is advised that athletes do not increase the intensity of the squat (i.e., increase resistance) unless the athlete can demonstrate consistent, proper form of the back squat. Specifically, the back squat is used first in the battery of squat variations to teach the parent movement pattern and identify functional deficits. If taught and progressed correctly, technique should remain the same as exercise intensity is increased. Part 2 of the discussion will detail corrective strategies to target specific functional deficits identified during the squat.

It should be noted that the back squat is only one recommended component of a comprehensive neuromuscular training program for youth. Integrative neuromuscular

training targeted for the physical development of youth should consider a variety of cognitive- and training-age appropriate exercises to adequately prepare a child for the rigors of moderate to intense physical activity (34,40). Integrative neuromuscular training programs for youth should be appropriately designed to meet the needs and goals of aspiring young athletes while considering their current ability level (24). It is highly recommended that qualified integrative neuromuscular training professionals who understand the psychosocial uniqueness of youth contribute to the design, supervision, and implementation of training programs for young athletes to minimize the risk of training-related injuries and to promote acquisition of sound exercise technique (24,34). Integrative neuromuscular training programs for youth are most effective when designed and progressed to be safe and training-age appropriate (11,34,35,41).

## **CONCLUSIONS**

The assessment of the unloaded back squat is meant to be a guide for trainers and coaches to identify and target corrections for biomechanical deficits of young athletes before participation in more advanced and intense physical training activities. By teaching and correcting optimal form of a basic functional movement inherent to many popular dynamic sports, an athlete can become more sufficiently prepared for the rigorous demands of physical activity. Furthermore, by instilling proper mechanics in youth, individuals may be more inclined to elicit optimal performance gains and reduce injury risk. It is recommended that instructors make careful observations during analysis of the squat assessment. These observations are imperative in developing individualized targeted corrective interventions. Part 2 of this commentary will cover targeted corrective training progressions and methodology for the common deficits for each criterion discussed in this manuscript (22).

Through identification and correction of functional deficits by the body-weight squat, practitioners can greatly assist young athletes to reap the benefits of improved performance and reduced injury risk to promote successful athletic careers and long-term physical well-being.

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