# Orthopedic Management of the Cross Country Skier

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## ABSTRACT

This monograph discusses the technique and injury management of the cross country (XC) skier. Primary XC skiing techniques and sub-techniques are reviewed in detail with video supplements for better understanding. Biomechanics are discussed for classic and skate sub-techniques. Common injuries, along with risk factors, are reviewed. Injury evaluation and treatment considerations specific to the XC skier are covered, with exercise recommendations, loading progression considerations, and a return-to-sport guideline for skiers of all abilities. Finally, medical race coverage recommendations are discussed for those providing on-site support. Four case studies related to common injuries seen in the XC skier population are presented. Each case outlines the skier's presentation, objective findings, management, and outcomes. The first case involves a 79-year-old female presenting to physical therapy with a concussion after a fall while XC skiing downhill at approximately 20 mph. The second case describes an 18-year-old competitive male skier referred to physical therapy for post-operative management of a Stener lesion and ulnar collateral ligament tear after a fall onto his hand while XC skiing. The third case outlines the management of a 12-year-old female XC skier presenting with anterior knee pain during off-season training, most significantly with running and roller-skiing. The final case summarizes a 17-year-old XC skier's plan of care before and after the surgical release of bilateral, lower leg anterior and lateral compartments due to compartment syndrome.

**Key Words:** biomechanics, loading progressions, return to sport, technique

## LEARNING OBJECTIVES

Upon completion of this monograph, the course participant will be able to:

1. Describe the biomechanics of classical and skate ski techniques and sub-techniques.
2. Identify differences between skiers using beginner technique versus advanced technique.
3. Understand the relevance of video analysis in examining and managing skiers using classic and skate sub-techniques.
4. Identify common pathologies seen in cross country ski athletes.
5. Apply recommended management strategies specific to the injured cross country skier.
6. Describe cross country ski gear and implications for symptoms or pathology.
7. Create an exercise program for a skier, integrating exercises to mimic the desired cross country ski sub-technique skill.
8. Evaluate training history, consider the skier's future training or recreational skiing goals, and implement a safe return to snow program.
9. Define key considerations for coverage of cross country ski events in the field.

## INTRODUCTION

Cross country (XC) skiing has been a means of travel and procuring food as far back as 2000 BC.[1] Early skis were made of wood with a pelt or strip of fur placed on the underside to provide grip, much like the evolved "skins" used today. Ski poles, initially crafted of pine, allowed for upper extremity (UE) balance and propulsion. Cross country skiing remains deeply woven into present-day winter culture, where skiers recreate and compete in winter sports across the globe. In the United States alone, 4.8 million individuals XC skied in the 2019-2020 season.[2]

Cross country ski technique is described as a cyclical, continuous synchronization of the UE, trunk, and lower extremities (LE)[3] to promote the effective transfer of energy to propel the body forward. Far more efficient than sinking each step into deep snow, skis displace body weight, allowing the skier to glide over the top of the snow. Ski poles driven into the snow offer improved efficiency by loading the UE, making XC skiing uniquely a "quadruped sport."[4] The skill of synchronizing ski cycles allows the skier to stay coordinated and maintain forward momentum. Like a walking or running gait, a skier's velocity is directly related to tempo and cadence; changing these spatiotemporal characteristics helps regulate a skier's speed. When altering tempo or cadence is not enough, variations in technique have evolved. These adaptations make up the classic or skate sub-techniques. An analogy of sub-techniques in XC skiing is the gearbox of a car. Cars must upshift and downshift while climbing and descending to maintain efficient forward momentum. *Changing gears* is a term used to describe a skier's ability to effectively use each sub-technique smoothly and efficiently to accommodate variability in the terrain.[5] Once a skier learns how to manage spatiotemporal characteristics and develops competence with sub-techniques, skiers of all ages and ability levels can learn to ski easy and moderate terrain efficiently.

To help clinicians better understand the skills required of recreational and expert skiers, this monograph will begin with a detailed overview of both major techniques of XC skiing - classical and skate. These major techniques will be broken down into common sub-techniques and the biomechanics involved. The authors will compare variations in sub-techniques found between beginner versus expert skiers within written text and tables. The clinician will then be introduced to video analysis and how to differentiate the variations of a beginner developing a new motor pattern from an expert technique.

Though XC skiing is a safe and low-impact sport, injuries do occur. Overuse injuries outnumber acute injuries but at lower incidence rates when compared to other sporting athletes.[6] After a brief introduction to gear, personal, and environmental factors acting on the skier, the focus of the monograph will shift to common injuries sustained by XC skiers both in-season and during cross-training. Afterward, sport-specific management will be discussed. Next, this monograph will introduce the use of a training and symptom log to make recommendations on training, exercise, and loading progressions as part of the return to sport continuum. Finally, the monograph will cover pearls for medical coverage at XC ski races and describe 4 cases of XC skier injuries intended to improve the clinical decision-making related to the management of skiers.

## TECHNIQUE AND BIOMECHANICS OF CROSS COUNTRY SKIING

Cross country skiing is divided into two primary techniques: classic and skate. Both classic and skate have their own sub-techniques (**Table 1**). This monograph will define these sub-techniques (**Tables 2-9** and **Videos 1-9**). To gain a further understanding of this complex sport, the reader can refer to these tables and videos when reading the text.

### Spatiotemporal Characteristics of Cross Country Skiing

#### Ski cycle

The *ski gait, or ski cycle,* is defined in research and coaching as including all 4 points of the UE and LE (via skis and ski poles), each making a single contact with the snow. The first contact on snow is often termed the *starting point* - when the pole makes its first contact in the ski cycle.[7–9] In the LE, the ski cycle is broken up into *glide phase, pushing phase,* and *retrieval.* The *glide phase* occurs when the stance ski is actively gliding forward on snow. This can be further broken down into the *starting position*, which is the initiation of the glide phase when the ski meets the snow, and the *preloading phase* when the skier is gliding and building potential energy in preparation to transition to the pushing phase. The *pushing or kicking phase* represents the transition from potential to kinetic energy to continue advancing the ski. This occurs through what is described as a resultant reaction (force) between the surface and the ski.[10] In skate skiing, this phase is called the *pushing*, *propulsion,* or *thrust phase.*[11] The *retrieval phase* is the moment when the weight is shifted from the stance ski to the contralateral ski, and the original stance leg is lifted off the snow and advanced to its starting position, similar to the swing phase in running.

In the upper body, the ski cycle begins with the *start position*. This moment is the initiation of a pole plant or ground contact, a transition from stored potential to kinetic energy of the UE and trunk over a more vertically oriented pole position. Next is the *poling* or *pushing phase,* which describes the brief period starting at the pole plant and transitioning to *propulsion* or push-off, where the poles are angled forward to an optimal position to push the body forward and through. The *retrieval phase* is when the arm swings forward to return to the starting position, again building potential energy in the trunk, scapulothoracic joints, and shoulder. Finally, in double poling (DP), double pole kick (DPK), V2, and V2 alternate (V2A), the term *high point* is used to reference the final position of retrieval for which all potential energy is gained before the pole plant or starting point.

#### Spatiotemporal terminology

Standard measures of the ski cycle are analogous to the gait cycle in running. Notable terminology with applications to the recreational skier are *ski cycle length,* which is the distance traveled in a full ski cycle. *Speed or velocity* is measured in meters per second relative to turnover of ski cycles. *F*or the recreational skier racing in citizen events is measured and recorded in race results as an average of time (minutes) skied per kilometer. The *rate of force development* (RFD)[9] adaptations the skier must put forth more quickly and over a shorter period of time, increase as the skier works to main-

**Table 1.** Sub-Techniques of Classic and Skate Skiing Terminology Used Most Commonly in North America

| Classic | Skate | Downhill Techniques (Both skate and Classic Skiing) |
|---|---|---|
| Herringbone (HB)<br>Diagonal Striding (DS)<br>Double Pole (DP)<br>Double Pole Kick (DPK) | Herringbone Skate (HBS)<br>V1<br>V2<br>V2 Alternate (V2A)<br>No pole skating | Snowplow<br>Tucking<br>Cornering |

tain momentum when climbing. This may have implications for exercise prescription, which should sometimes include power-focused interventions.

**Spatiotemporal characteristics within the ski cycle**

The multiple sub-techniques of classical and skate skiing allow the skier to adapt to terrain and speed by choosing the best sub-technique for the ski trail's flat, hilly, or downhill sections. Cross country skiing is physically demanding and though aerobic in nature, may call for anaerobic efforts when working harder to master the more challenging skills, such as climbing. As skiers become more proficient with their technique,[12] they also become more efficient and can maintain the fastest sub-technique over more variable terrain. For example, the least efficient but most stable technique for hill climbing is the herringbone (HB) sub-technique. A beginner will use HB more often as it is the steadiest, while an expert will only use this technique for the steepest climbs. Therefore, the most stable techniques are taught first with altered spatiotemporal characteristics to best maintain balance. A systematic review by Zoppirolli et al[5] showed that maximizing the length of a ski cycle is advantageous for efficiency and performance across all sub-techniques exhibited by expert skiers. A longer ski cycle is achieved by using mechanically favorable poling and ski angles, allowing for more recovery time in the retrieval phase. In the less experienced or beginner skier, the ability to maintain a long glide length is affected by balance, technique aptitude, and adapting to the terrain. For example, a longer cycle *length* is more easily maintained on flat versus hilly terrain. Increasing the cycle *rate* will allow for faster speeds on flat terrain. An increased cycle rate is also necessary to meet increased force and power demands when skiing uphill.[13] Though cycle length will be longer on flats and shorter going uphill, *maximizing* the cycle length over all types of terrain reflects an advanced skier's technical aptitude. The advanced skier balances high, rapid force-generating capacity for propulsion and muscle endurance to maintain balance during a long glide phase. A beginner skier will be less capable of maintaining cycle length and will make more frequent changes to their sub-technique on rugged terrain. Beginners may also rely on a double base of support (BOS) rather than balance on a single ski in the glide phase.

## Muscle Activation in Cross Country Skiing

Following is an overview of the primary muscle groups involved in the XC ski cycle, starting with retrieval and ending with the pushing phase.

**Shoulder**

Cross country skiing requires load-bearing demand through the ski pole, which supports balance and timing, and propulsion for intermediate and advanced skiers to advance forward. A diagonal stride requires movement within or just outside the sagittal plane. Double pole, DPK, V2, and V2A require shoulder elevation in the scapular plane and internal rotation to maintain a narrow hand placement. Herringbone and V1 techniques require a broader hand placement with greater variability in shoulder rotation to adapt to a wider ski angle.

Within the retrieval phase, the UE takes advantage of a moment of recovery. The UE is relaxed as the arm swings forward with the momentum of the skier, then shifts to open chain elevation using concentric action of the shoulder flexors, scapular stabilizers, deltoids, and rotator cuff (RTC) to bring the shoulder into flexion to prepare pole position for the next ski cycle. As the potential energy shifts to kinetic energy upon loading in the pole plant, the humerus is fixed via the hand gripping the ski pole, grounded in the snow. This is an example of concave (glenoid) on convex (humeral head) motion with arthrokinematics unique to sports requiring closed-chain activation of the shoulder. As such, under the load of the ski pole in snow, the scapulothoracic joint must depress and retract, with key players being the latissimus dorsi, rhomboids, posterior deltoid, and middle and lower trapezius muscles[14] to pull the body forward through shoulder extension.

**Elbow**

The elbow flexors concentrically flex in an open chain at the completion of the retrieval phase just before the pole meets the snow. At the pole plant, the XC skiing technique uses the elbow flexors' and extensors' capabilities to generate high peak isometric torque at the most advantageous angles of elbow flexion,[14] reported in XC skiing as between 95.7° ± 9.2° and 103.4° ± 12.2° in elite skiers.[15] This activity transitions quickly to concentric, closed-chain elbow extension in the propulsion phase. Targeting the triceps' strength is valuable because the long head of the triceps muscle extends and adducts the shoulder to bring the trunk through in the pole-pushing phase.

**Wrist and Hand**

Upon retrieval, the hand and forearm muscles are relaxed. Upon loading in the pole plant and pushing phase, the hand's extrinsic flexors and extensors work as a force couple to withstand the force required to stabilize the wrist and propel the skier forward. This strong, stable, near-neutral hand position will transition to some ulnar deviation[16] at the end of the pushing phase.

**Breathing**

The overall function of the trunk musculature is to provide stability of the axial skeleton and the trunk[14] and assist with ventilation. The primary muscles of inspiration are the diaphragm, scalenes, and intercostals. With exercise, the diaphragm acts as a "flow generator," with the abdominals and intercostals acting on the necessary pressures of increased respiratory rate. Upon inhalation, the intercostals contract to limit the pressure on the rib cage from the diaphragm while the abdominal muscles lengthen. This is reversed during exhalation.[17] Of note, it has been shown that women trained in endurance sports have harder work breathing due to airway size than their male counterparts, possibly due to smaller lung and airway size.[18] Perhaps this explains the variability in $VO_2$ max or aerobic capacity between men and women. Because skiing requires significant muscular contributions of the trunk to control the extremities, concurrent with its high cardiovascular demand, breathing assessment may be valuable, especially in those with symptoms in the cervical and thoracic spine or shoulder and in women postpartum.

**Thoracic spine, lumbar spine, and trunk**

Cross country skiers are likely to move through greater degrees of flexion and extension range in the lumbar and thoracic spine when using classic techniques and are less likely to use end-range motions while skate skiing. Classic skiing requires a complex movement pattern consisting of coordination between the ipsilateral and contralateral sides, mainly in the sagittal plane and all planes in skate skiing. This task demands the synchronous function of the intrinsic and extrinsic muscles of the trunk and all four extremities. In the retrieval phase, some of the primary muscles involved in concentric extension are the erector spinae muscle group, multifidi, and latissimus dorsi due to their known contributions to thoracolumbar extension and rotation.[14] In UE and LE pushing phases, the erector spinae muscle group and multifidi shift to eccentrically control the trunk as the abdominals (rectus abdominis and oblique abdominal muscles) engage in powerful concentric trunk flexion. The best example is the DP technique, for which the skier draws heavily on abdominal flexion to generate power in the poling phase. Excess forward trunk lean or hip hinge in beginners may result from abdominal weakness, hip weakness, balance difficulties, or abnormal lumbopelvic rhythm.

**Hip**

The hip is the powerful anchor of the limb, providing balance, stability, swing, powerful kick, and propulsion in XC skiing. In the sagittal plane, the hip flexors work both in the open and closed chain. During the retrieval phase, the hip flexors and abdominal force couple work to flex the hip concentrically, whereas during the glide phase, these muscles work eccentrically. Key players in hip flexion are the iliopsoas and the rectus femoris muscles. Additionally, the adductor muscles adduct and stabilize the hip, assist in flexion and extension, act as secondary internal rotators, and are theoretically active in all phases and planes in XC skiing. Evaluating, quantifying, and ensuring hip adduction strength is warranted in rehabilitating any LE injury. Once in the pushing phase, the hamstrings and gluteus maximus muscles[14] allow for transition into concentric hip extension while climbing, with hamstrings contributing more on gradual hills and gluteus maximus muscle contributing on steeper climbs. The concentric and isometric activation of the hip abductors will be called upon for the pushing and propulsion phase in skate techniques in conjunction with the hip external rotators. The overall function of the external rotator muscle group is to control the pelvic-on-femoral position. This muscle group functions while one leg glides concurrently with contralateral LE push-off in skating.[14] Additionally, the requirement to adapt to the terrain, descend with control while turning, for example, is similar to this muscle group's role in change-of-direction and cutting sports. In the treatment of the hip, the authors of this monograph recommend objectively quantifying hip strength. Though we are unaware of any available literature on XC skiers, adductor and abductor ratios have been studied in hockey players using dynamometry.[19] This allows the therapist to measure changes in strength objectively throughout the rehabilitation process.

**Knee**

In the retrieval phase, the rectus femoris muscle assists in open-chain hip flexion and knee extension. Upon positioning the ski on the snow in the gliding phase, the knee acts with the hip and the foot to position the limb based on the pace and slope of the trail. Reliance on eccentric control of the quadriceps muscle is observed when descending, as in alpine skiing. Knee extensors engage in powerful closed chain extension on flats and when climbing. The hamstrings and hip adductors play an essential role as stabilizers and in rotational control of the knee,[14,20] tested by balance requirements while gliding on snow.

**Ankle and Foot**

The muscles of the ankle and foot respond to the proximal biomechanical and active forces in XC skiing. In classic skiing, the action of the lower leg mimics running, with the ankle dorsiflexors concentrically acting to clear the ski in retrieval. In skate skiing, additional concentric contributions of the evertors are required to prevent the tip of the ski from tipping laterally and catching in the snow. It is the authors' observation that this is one of the ways XC skiers develop exercise-related leg pain. However, upon loading the ski on the snow, muscles from all 4 compartments (anterior, posterior, deep posterior, and lateral) are engaged throughout the gliding phase.[16] Finally, at the end of push-off and propulsion in both techniques, the primary contribution shifts to the ankle plantar flexors. The glide phase requires activating the foot intrinsics and muscles of all 4 lower leg compartments to stabilize the gliding. A balanced and stable foot position is necessary to adapt to the terrain and maintain a flat ski to glide. Therefore, constant co-contraction of muscles of all 4 compartments would limit the subtle yet important skill of adapting to the snow surface, slope, and terrain.

## VIDEO ANALYSIS

As with running, video analysis is a helpful way to identify dysfunctional movement patterns contributing to the skier's complaint. Even without XC skiing experience, basic knowledge of the technique will provide the physical therapist with helpful comparisons to guide treatment in the clinic and on snow. As in any sport, beginner technique has typical inconsistencies due to continuous growth and development. These beginner variations are not necessarily tied to injury risk. More importantly, they provide the physical therapist with a spectrum of normal movement variability during this skill's initial motor learning phases. When these beginner variations are related to symptomatic movement, asymmetry, or injury, video analysis can help in the diagnostic process. As part of treating an injury, knowledge of the technique will allow the physical therapist to observe and recreate desired motor patterns in a clinical setting. Please review the advanced and beginner technique variations and the individual sub-technique sections and tables to pull the most out of the video analysis.

### Frontal Plane View

Observations in the frontal plane allow the physical therapist to identify and appreciate the coordination and timing of the UE and LE. In the UE, one can observe reliance on poles for balance versus using the UE for propulsion, which takes more skill. Observe hand placement, shoulder abduction angles, center of mass (COM) displacement, or lack of control at the LE, often due to strength deficits at the hip or strength and balance difficulties in the ankle/foot.

### Sagittal Plane View

From the sagittal plane view, the physical therapist can appreciate joint angles from head to toe and how the skier leverages their COM and weight distribution over the skis. One can observe the technique's coordination and timing relative to the terrain's angle and the skier's ability to get an effective kick or propulsion in the pushing phase. In the UE, the physical therapist can observe a skier's pole angle, most easily viewed by the hand placement and position of the tips of the poles relative to the skier's feet. The physical therapist can see the position of the trunk and if the skier can use motion in the sagittal plane to maintain an advantageous trunk and hip position relative to their feet. In the LE, the clinician can observe if the skier can glide in a single-leg stance. Finally, note that the physical therapist can only make assumptions of rotational control from either vantage point. For example, in the sagittal viewpoint, transverse plane assumptions can be made if the far side shoulder and chest become visible to the viewer.

## CLASSIC SKIING SUB-TECHNIQUES

Relevant biomechanical data highlighted in each XC skiing sub-technique section below is based on small cohorts of elite, highly trained, primarily male skiers in their 20s and 30s in laboratory settings and at high speeds.[5] This cohort of skiers generally are strong, have superior fitness, and can put forth high UE and LE forces. As such, these data may lack applicability across age, female sex, and various ability levels. When considering treatment of the competitive recreational skier (ie, junior, high school, or master skiers), note that even elite skiers, who are highly trained, with impressive aerobic capacity ($VO_2$ max output), strength, and force output, must develop their technique to compete successfully. In research, these variables are defined as economy and gross efficiency.[21] For the physical therapist, improving a skier's ability to synchronize and coordinate the UE, trunk, and LE can contribute favorably to results at any age or ability level.[12,21,22] The following sections will highlight the specifics of the most common XC skiing sub-techniques and allow the reader to understand the muscular demands, coordination, and strength required of the skier after injury.

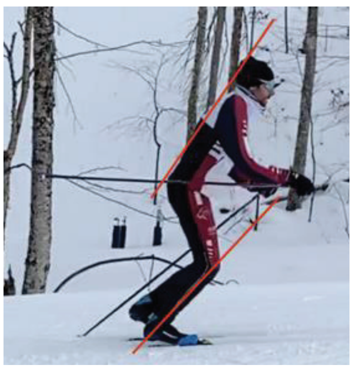
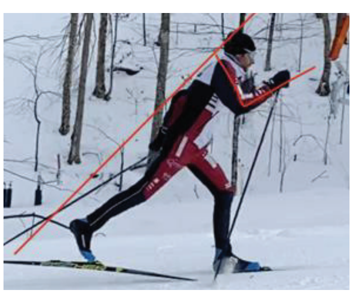
### Diagonal Striding Sub-Technique

Diagonal striding (DS, illustrated in **Table 2**), also called classic striding, is the sub-technique most closely related to running due to the upper and lower extremity's reciprocal action, or out-of-phase movement.[23] The bindings on the ski enable a free, unattached heel, allowing a push-off in plantar flexion similar to running. *Striding* is a sub-technique used on flat and uphill terrain, most often in groomed parallel tracks. Beginners stride on flat terrain, whereas elite skiers are more efficient and often DP on flat terrain and stride on slopes steeper than 6°.[24] In the UE, the poling cycle occurs ahead of the kicking phase in the contralateral limb, with the trunk coordinating the appropriate contralateral rotation of the upper and lower extremity. Advanced skiers use poling to coordinate timing, balance, and propulsion to advance. Beginner and intermediate skiers will demonstrate a less forceful kick and use ski poles as a tool for balance more than for propulsion.[25] Though trail running, hiking, or snowshoeing with ski poles may draw some comparisons, classic striding is unique because the advanced skier generates potential energy in preparation for the kicking phase while gliding in a single-leg stance. In contrast, a defining mark of the beginner is double leg support to maintain balance in preparation for the kicking phase, as shown in **Video 1** (classic beginner technique) and **Table 2**. Approaching the end of the glide is the pre-loading phase (potential energy) that transitions to the kicking phase (kinetic energy). This process, the point of greatest force generation in the LE, is unique to DS and occurs primarily in the sagittal plane. This is analogous to the breaking and propulsive phases in running. At this point, the forces generated by the LE of the skier compress the Nordic camber, stop the ski briefly, and grip the snow to advance. This force must occur more quickly and deliberately at a faster pace or higher incline.[25,26]

#### Forces in diagonal striding

In the UE, Andersson et al[23] found that forces measured through ski poles ranged from 14-86% body weight (BW). In addition, RFD during the poling phase can be up to 5-6x higher at maximal speed in the same cohort. It was also found that a more prolonged and balanced distribution of pole force is

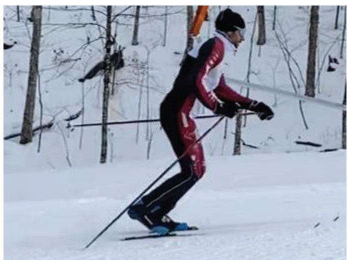
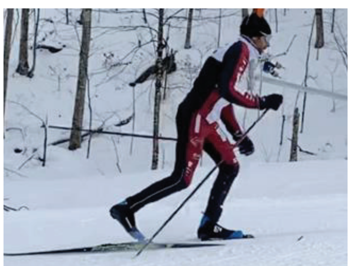
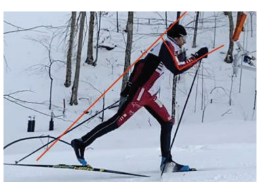
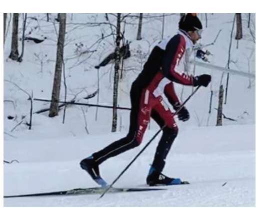
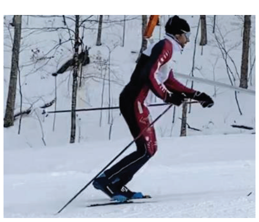
**Table 2.** Classic Sub-Technique - Diagonal Striding
Please refer to the following videos: **Video 1**, Classic Technique – Beginner; **Video 2**, Classic Diagonal Striding Sub-technique - Advanced

| Proper Technique Image | Proper Technique | Video Analysis<br>Typical Beginner Variations |
|---|---|---|
| **Starting Position -<br>Left Leg**<br> | **Starting Position - Left Leg**<br>• Shoulders and hips level<br>• Kicking foot should be fully weighted and the retrieval leg is un-weighted<br>• Parallel trunk and tibia<br>• Weight forward, hips further forward than the heels<br>• Hands at approximately waist height | **Sagittal**<br>• Asymmetry observed in trunk and tibial angle may indicate poor weight distribution which often appears as a more forward flexed trunk, a greater hip angle and hips behind heels<br>• Decreased ankle dorsiflexion angle<br>• Reduced shoulder and elbow angle appearing like hand is "punching or pushing" forward at end of swing phase<br>• Double base of support that may appear like shuffling gait<br><br>**Frontal**<br>• Shoulders and hips are not parallel<br>• Over-rotation at shoulders or trunk<br>• Indication of lower extremity (LE) double base of support<br>• Limited frontal plane control of LE |
| **Glide Phase -<br>Left Leg, Right Arm**<br> | **Glide Phase - Left Leg, Right Arm**<br>• Kicking leg (right leg in picture) pushes into full extension behind the skier while left, gliding leg, drives forward in preparation for left kicking phase<br>• Forward, right, poling arm at approximately 90º at completion of swing or retrieval phase, pole tip strikes the ground next to the forward, left foot. The arm that has completed poling should be in a relaxed, finish position<br>• Well balanced glide will allow for a more controlled and upright trunk, hip at advantageous angles and forward posture over foot and ankle; increased shoulder and elbow angle in preparation for pole plant | **Sagittal**<br>• Beginner will demonstrate a more forward flexed trunk, less shoulder angle and pole plant behind the stance or kicking leg<br>• With a reduced shoulder and elbow angle, forearm should appear closer to angle of shaft of ski pole<br>• Indications of limited glide and uncoordinated timing. Without a strong vertically oriented kick, and without forward body position, it will be more difficult to maintain forward momentum illustrated in a longer glide phase<br><br>**Frontal**<br>• Beginner will struggle to maintain LE transverse and frontal stability while gliding |

**Video 1: Classic Beginner Technique**
https://www.orthoptlearn.org/mod/vimeo/view.php?id=855467234

**Video 2: Classic Diagonal Striding Sub-technique— Advanced**
https://www.orthoptlearn.org/mod/vimeo/view.php?id=855462251

**Table 2.** *Continued*

| | | |
|---|---|---|
| **Pre-Loading and Kick Phase - left leg, right arm**<br><br> | **Pre-Loading Phase**<br>• The foot that the skier was gliding on (left in this picture) becomes the preloading and kicking ski. Forward gliding of that ski stops, all weight begins to transfer onto the gliding ski to preload the kick<br>• The gliding, and now preloading foot, is just in front of the center of mass to accommodate for the skier's forward momentum<br><br>**Kicking Phase**<br>• The kicking foot (left) will become fully weighted as the skier's center of mass transfers vertically over the foot, providing traction and grip over the snow. This will appear as hip stacked over heels and an increased tibial angle (into dorsiflexion). Ski stops briefly, then force production is directed posteriorly, from the flat foot position to ankle plantar flexion and metacarpophalangeal joints extension for final propulsion or push off | **Sagittal**<br>• A beginner will have a more vertically displaced, heel weighted load over the ski versus the notable ankle dorsiflexion angle seen here in the picture, this reduces the forces sustained while "setting" the Nordic camber (stopping the ski) and will keep forces driven more posteriorly<br><br>**Frontal**<br>• Heavy reliance on ski poles for balance, limited transverse control in trunk during out of phase upper extremity (UE) and LE movements in stride<br>• Beginners may be unable to fully transfer weight and will maintain some level of double base of support<br>• Limited frontal and transverse plane control of LE, often seen as excess valgus angle at knee |
| **Retrieval Phase skier's right leg and left arm**<br><br><br> | **Retrieval Phase**<br>• A relaxed swinging arm and leg along with a fully weighted kicking ski will bring the skier into a new starting position<br>• While the skier's body weight is positioned on the kicking ski, the unweighted swing leg can drive forward freely (retrieval phase). Proficient classic skiers swing their non-kicking leg forward rather than sliding it forward. | **Sagittal**<br>• A beginner may not be able to release the ski pole at completion of poling phase<br>• Swing phase may be less relaxed with increased elbow angle swinging through<br>• A beginner is often seen reaching or driving arm forward with similar shoulder angle, but less of an elbow angle at completion of swing phase<br>• Sliding a foot forward on the snow is a sign of inadequate weight transfer or lack of balance on (contralateral) glide leg<br><br>**Frontal**<br>• Loss of balance on glide leg may appear like trunk lean in retrieval phase or wider hand position of planted and swinging pole |