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An Evidence-Based Videotaped Running Biomechanics Analysis

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INTRODUCTION

Running is an extremely common form of exercise, whether recreational or competitive. However, running injuries are also quite common. In particular, running injuries such as patellofemoral pain, iliotibial band syndrome, and stress fractures to the tibia and metatarsals have been identified as highly prevalent in runners.[1] Although causative factors of running injuries are undoubtedly multifactorial, most agree that running biomechanics play a key role in injury development.

Numerous recent studies have identified abnormal biomechanics in persons with specific running injuries.[2–5] However, the vast majority of these studies used advanced technological methods, which are expensive and uncommon in standard clinical practice. Although some variables associated with running injuries require high-tech equipment, such as instrumented treadmills and 3-dimensional (3D) motion capture systems, many of the kinematic abnormalities identified in runners with injuries can be measured using a simple 2-dimensional (2D) video-based running analysis using readily available and fairly inexpensive tools.

The objective of this article is to provide a framework for a systematic video-based running biomechanics analysis plan based on the current evidence on running injuries. Although some of the proposed variables of interest ill have an impact on running performance, the primary focus of this analysis plan is to identify biomechanical factors related to common injuries in runners. Furthermore, there are many other factors that may be related or even causative for injuries while running, including training errors, current health status (ie,

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recent injury), and/or structural abnormalities (ie, leg length discrepancy, pes planus foot deformity etc).[6,7] However, the focus of this review is restricted to running kinematics, particularly those in the sagittal and frontal plane, which may be easily viewed with standard 2D video. A running biomechanics analysis should be an integral component of the evaluation, either for the injured runner or for screening for injury prevention, to complement a physical examination and thorough history.

ANALYSIS SETUP

Treadmill Setup

Although some studies have identified small differences in treadmill running when compared with overground running, these differences have mostly been associated with muscle activation patterns and joint forces.[8,9] In general, kinematic patterns during treadmill running are very similar to those observed during overground running.[10–12] As such, performing a video-based analysis of joint kinematics while running on a treadmill should provide valuable insight into running kinematics during overground running and is more practical for performing this evaluation.

Running velocity affects lower extremity kinematics.[13] Therefore, matching treadmill speed to a similar speed at which an injured runner experiences symptoms should be accommodated if possible. When evaluating a symptom-free runner, 1 strategy that can be used is to set the treadmill speed to match the running velocity of the runner when performing a “long run,” which is a common term used for the longest distance run in the recent past. The rationale for selecting this speed is that if runners are demonstrating abnormal biomechanics while performing longer runs, these faults will accumulate over the longer exercise period and may contribute to running injuries.

Cameras

Many high-definition cameras are available at varying price points. Both image resolution and temporal resolution should be considered when selecting cameras for video-based movement analysis. Many video cameras have excellent image resolution, but are limited to 30 frames per second. Cameras with higher frame rates (eg, ≥120 Hz) can provide cleaner images that are easier to evaluate and more appropriate for the evaluation of running kinematics. More recently released smartphones and tablets can be adjusted to acquire video at high frame rates and provide adequate video for this purpose.

Views

When performing a video-based analysis it is recommended that, at a minimum, 2 orthogonal (at right angles to each other) views are included. The analysis provided in this article uses a lateral view and a posterior view. Others may include an anterior view or lateral views from both sides. Multiple views from each camera, including zoomed-in views on the foot and ankle as well as zoomed-out views of the entire body, can be helpful. Many of these preferences will need to be modified to work within the constraints of the clinical environment. Maintaining a reproducible camera location and a fixed orthogonal angle to the treadmill is important to performing a reliable analysis. Recent studies have found the reliability of a single camera analysis to vary significantly, with some metrics showing excellent reproducibility (knee flexion, rear foot kinematics) and others demonstrating poor reproducibility (heel-to-center of mass distance).[14] There is also evidence that experience can improve the reliability of measurements made on video-based kinematic evaluations, so it is important for the clinician to practice running evaluations regularly to improve reliability.[15]

Markers

Application of markers for identification of anatomic landmarks can be useful when performing a video-based running analysis. These markers need not be expensive retroreflective tape-based markers. Any bright colored tape can be used for this purpose. Whenever possible, tape should be applied directly to the runner's skin. This is imperative when performing research-level 3D motion analysis. However, adapting these methods for use in a clinical setting may require markers over clothes. In these situations, it is recommended that the runners wear tight-fitting running sportswear to minimize the movement of the markers from clothing during running. In the images presented throughout this article, the following landmarks are identified and marked: C7 spinous process, posterior superior iliac spines, anterior superior iliac spine, greater trochanter, lateral knee joint line, lateral malleolus, midpoint of the calf, superior and inferior portions of the heel shoe counter, and head of the fifth metatarsal. This is an example of a common set of anatomy landmarks that are useful to evaluate during running and can be modified to suit the needs to the evaluation.

Warmup and Analysis Plan

It is advisable to allow for a period of time for the runner to run on the treadmill at the target speed to accommodate to the environment. Studies have identified changes in kinematics deviating from normal running mechanics with treadmill running up to the initial 6 minutes.[16] Therefore, an acclimation period of 6 to 10 minutes should be used when possible before evaluation. It is also important consider the nature of symptom provocation in an injured runner. If a runner experiences symptoms after a number of minutes or miles, it may be necessary to acquire video with the runner in a fatigued state, after a period of running and consistent with their symptom history.

When performing a movement analysis of any type, it is critical to execute the analysis systematically. We present a distal-to-proximal analysis plan. The order of the evaluation is not critical. However, it is extremely important to perform the entire evaluation, including all segments, joints, and whole body variables consistently, to avoid missing subtle yet potentially important kinematic abnormalities. Although numerous freeware options exist with extremely helpful tools for measuring biomechanical variables on running video (angles, distances, etc), it is generally not necessary. Most of the metrics in this article can be easily identified visually on slow motion video, or evaluation when progressing through the video frame by frame. To date, cutoffs for kinematics to be identified as abnormal, or predictive of injury, do not exist. As such, the analyses included here does not provide the reader with specific angles or measures that are "abnormal." Each metric is described, and indicators of normal kinematics are provided. It is the responsibility of the evaluator to determine what threshold for normal and abnormal should be applied to an individual runner and associated with the biomechanical contributor to injury.

Phases

It is important to identify specific moments within the running cycle that can be used for evaluation. Many of the phases of the running cycle are clear. However, particularly for evaluating stride mechanics, it is important to differentiate between video frames of rapidly evolving events. Take, for example, the images provided in Fig. 1. Fig. 1A is the final frame of the swing phase, Fig. 1B displays initial contact, and Fig. 1C displays loading response (which is identified by the presence of shoe deformation in the image). Different kinematic variables are evaluated on images from different phases of running. It is important for the evaluator to become familiar with identifying each of these phases (and others as described elsewhere in this article). Inconsistent identification of phases of running in evaluating biomechanics of running gait will make performing a reliable analysis impossible.

SIDE VIEW

Foot Strike Pattern

Identification of foot strike pattern can be easily performed on slow motion video or by evaluating video in a frame-by-frame manner (Fig. 2). It is recommended to always confirm foot strike pattern in this fashion, because even after considerable practice, it is not uncommon to misidentify a foot strike type when observing running at full speed. Foot strike types can be categorized as forefoot strike (FFS), midfoot strike, and rear foot strike. Recent literature suggests that video-based identification of foot strike patterns by a single rater are highly reliable, although interrater measures was found to be less reliable.[17] At this time, there is limited evidence that any 1 foot strike pattern is more or less likely to cause a runner to sustain an injury. However, this is an area of active research and data on this issue are emerging.[18,19] One study on competitive collegiate runners suggested that runners with a rear foot strike pattern developed more repetitive overuse injuries when compared with runners with an FFS pattern.[20] And although these finding suggest possible association between foot strike patterns and running injuries, more work is necessary before broad conclusions on foot strike recommendations can be made to modify injury risk.

Foot Inclination Angle at Initial Contact

The angle created by the sole of the shoe and the treadmill belt is noted as the inclination angle of the foot (relative to a global coordinate system, not the tibia) at initial contact (Fig. 3). This variable is not applicable for midfoot strike and FFS runners.

A recent study by Wille and colleagues[21] found inclination angle to be particularly important in estimating ground reaction forces and joint kinetics during running. Specifically, increased foot inclination angle was found to be related to higher peak knee extensor moments, increased knee energy absorbed, higher peak vertical ground reaction force, and greater braking impulse during running. Each of these variables has been implicated in injury biomechanics, suggesting that a very high foot inclination angle at initial contact may not be desirable. This may be a source for intervention in runners who experience injuries associated with high ground reaction forces or excessive joint kinetics. There are no cutoffs at which this angle is determined to be abnormal. Rather, it is likely on a sliding scale, where lower values are generally associated with lower ground reaction forces and joint kinetics, and higher values as associated with increased forces. However, it should be noted that a high foot inclination angle in isolation may be a benign finding and needs to be evaluated in the context of the entire running evaluations (see Overstriding).

Tibia Angle at Loading Response

The vertical alignment of the lower leg during loading response can be a valuable indicator of stride mechanics. Video of the runner should be evaluated using freeze-frames at the moment of loading response (as the shoe begins to deform just after initial contact). The alignment of the lower leg relative to a vertical line in the video field of view can be evaluated easily. An extended tibia is identified when the lateral knee joint marker is posterior to the lateral malleolus marker (Fig. 4A). Conversely, a flexed tibia is identified when the lateral knee marker is anterior to the lateral malleolus (Fig. 4C), and when these 2 markers are directly vertical to one another, this would be identified as a vertical tibia (Fig. 4B). For a runner that suffers from impact-related running injuries, an extended tibia is not ideal. A vertical or flexed tibia allows the runner to dissipate impact more readily though knee flexion.

Similar to foot inclination angle, the tibia angle in itself may not be meaningful in isolation. It is a variable that can be grouped in a series of stride mechanics variables to better describe the characteristics of the runners stride and biomechanical risk profile.

Knee Flexion During Stance

Peak knee flexion angle during stance may occur at slightly different phases in different runners. It is recommended to scroll through stance phase frames to identify maximum knee flexion. Key aspects of knee flexion during stance include the peak amount of knee flexion and the knee joint excursion during stance (difference in angle from initial contact to peak knee flexion). In general, normal peak knee flexion approaches approximately 45° at midstance (Fig. 5). Although explicit cutoffs have not been developed for this variable, a runner who demonstrates considerably less than 45° of knee flexion may suggest reduced shock absorption, and intervention may be warranted. Some data exist suggesting that lower knee flexion (<40°) may be associated with certain subgroups of patients with patellofemoral pain.[22] Knee stiffness, a variable that includes both reduced knee flexion and/or increased knee flexion moment during stance phase, may be associated with tibial stress fractures.[23]

Hip Extension During Late Stance

Reduced hip extension during late stance is a common observation in the recreational runner (Fig. 6). It is traditionally believed that lack of hip extension may be associated with reduced flexibility of the iliopsoas muscle. However, the optimal amount of hip extension during running remains elusive. It is possible that the required amount of hip extension is not the same for each runner, but related to other characteristics of their running form. For example, a fairly slow runner may have a very compact stride, demonstrate approximately 10° of peak hip extension and not require any intervention. However, a different runner, with a long stride and perhaps a faster pace, may also have approximately 10° of hip extension, but also concurrently demonstrate a significant overstride pattern (landing with the foot out in front of the center of mass) with higher impact loading and braking forces. The latter runner may require stride modification or improved hip extension during running to modify these forces that could contribute to injury. Commonly observed compensations for persons with reduced hip extension include (1) increased lumbar spine extension, (2) bounding, a strategy to increase float time to increase overall stride length in the absence of adequate hip extension, (3) increased overstriding, including excessive reaching during initial contact as a strategy to increase stride length, and (4) increased cadence to increase running speed in the presence of a limited hip extension.

Trunk Lean

Trunk lean is a variable that has received little attention in the scientific literature. However, this is not the case in the popular running non–peer-reviewed literature. Many running styles, including ChiRunning, pose running, and even barefoot running have included cues for novice runners to increase trunk lean. A focus on leaning "from the ankles," rather than increasing hip flexion to achieve the trunk lean, seems to be a priority for some styles. Many running experts suggest that trunk lean is a key component to correct running posture. However, very little has been done on the research side of this issue. A recent article by Teng and Powers[24] demonstrated that a small increase in trunk lean (~7°) resulted in a significant lowering of the stress across the patellofemoral joint without a significant increase in ankle demand, suggesting that this strategy may be important for runners with patellofemoral pain. The overall findings were that reduced trunk flexion (more upright posture) was associated with greater knee loads. In contrast, increased trunk flexion shifted demand away from the knee joint, and to the hip and ankle (although the latter was not statistically higher).[25] However, the authors warn that this study was performed in healthy subjects and more work is necessary to understand the relationship between trunk lean and running injuries. Furthermore, the authors noted that the trunk lean in these subjects was not purely from the ankles, as is recommended by some running styles, but rather a combination of hip flexion, pelvis anterior tilt, and other small kinematic adjustments. Nonetheless, evaluating trunk lean in runners may become an important variable as additional research emerges (Fig. 7).

Overstriding

Increased stride length has been found to be associated with an increased risk of tibial stress fractures in runners.[5] However, it is likely that a long stride is not the cause of high impacts associated with stress fractures and other running injuries. Rather, the presence and magnitude of overstriding may be the key risk factor. Many accomplished runners with very long strides have large amounts of hip extension without the presence of overstriding. It can be argued that these runners are not at risk for the injuries associated with high impacts.[26] It is important to differentiate stride length from overstriding in this context. Overstriding is a description of a running pattern in which the foot lands in front of the person's center of mass, and is associated with reaching, including hip flexion with knee extension, before initial contact. A recent study by Wille and colleagues[21] identified a metric that is closely related to overstriding—the distance from the heel at initial contact to the runners center of mass—is a significant predictor of knee extensor moment (the sagittal plane torque across the knee joint during stance) and braking impulse (an important contributor to shock attenuation and running energetics) during running. These data strongly suggest that overstriding is an important kinematic metric to consider when advanced technology, such as force platforms or tibia accelerometers, are not available.

As discussed, overstriding can be evaluated through a variety of metrics. Supportive measures such as the foot inclination angle at initial contact, tibial angle at loading response, and knee flexion at initial contact can inform the clinician about the tendency for overstriding. Ultimately, 1 strategy for determination of overstriding on video can be assessed by evaluating the runner at loading response.[27] By drawing a vertical line from the runner’s lateral malleolus and extending upward, the relationship between the ankle position and the pelvis can be evaluated. Ideally, the vertical line will fall within the runner’s pelvis, indicating that the foot is landing under the center of mass of the runner (Fig. 8A). If the vertical line is observed anterior to the pelvis (Fig. 8B), this indicates an overstride. Note that this dichotomous metric is not without limitations. In particular, it does not account for trunk flexion angle, which impacts the actual center of mass of the runner, and may be less useful for runners with a midfoot strike or FFS. Nonetheless, it is a very useful tool for identifying the presence of overstriding in runners.

Vertical Displacement of the Center of Mass

The vertical displacement of the center of mass is a very important metric to evaluate in runners. It is easily measured by comparing frames of video from the runner’s highest point during float, to the lowest point during stance (Fig. 9). There are inherent errors in measuring this variable, because the actual location of the center of mass is impossible to assess on video. One strategy is to identify a location on the runner’s pelvis and then to use this as a surrogate for the center of mass. Vertical displacement during running has key implications for injury mechanics as well as energetics. Increased excursion of the center of mass vertically has been found to be predictive of the peak knee extensor moment, the peak vertical ground reaction force, as well as braking impulse during running, all very important variables in running mechanics.[21] This variable can become a problem in “bounders,” runners who increase float time, often in response to other deficits (eg, reduced hip extension). The end result is increased work required by the runner to perform this type of running. It has been found that increasing cadence by 10% during running can reduce significantly the vertical displacement of the center of mass.[28]

Additional Variables

Auditory—A lot of information can be gathered from the sounds made during running. Certainly, auditory information differs between treadmills and runners of varying sizes. However, the clinician can quickly calibrate the normal or typical impact sounds of their treadmill, and this can be very useful in gathering information about impact during running. Greater noise with striking the treadmill may be associated with higher impact forces. In addition, asymmetries can quickly be identified by listening to the foot strike patterns of the runner. All of this information can be very valuable for a biomechanics running analysis.

Shaking of the treadmill—In addition to auditory information, the reaction of the treadmill at the time of impact can also provide important information. Some large, sturdy treadmills may not provide this information, but many models provide differing amounts to shaking or giving way in response to impact, and this can be very informative to the observant evaluator.

Cadence—The step rate, or cadence, should be evaluated in all runners. This variable is easily measured in a variety of ways. One strategy is to count the number of right heel strikes over a 1-minute period. This number is equivalent to the "stride rate." Multiplying this number by 2 equates to the "step rate." Several recent studies have evaluated the biomechanical consequences of manipulating cadence.[28–32] These data suggest that an increase in cadence can result in several biomechanical changes in running form, many of which may be desirable in specific runners. For example, it has been demonstrated that increasing cadence by 10% can reduce center of mass vertical excursion, braking impulse, and mechanical energy absorbed at the knee, as well as decrease peak hip adduction angle and peak hip adduction and internal rotation moments during running.[28] The optimal cadence has been an area of debate, with some suggesting that approximately 180 steps per minute being ideal. However, the majority of support for this comes from running economy studies, not studies on injury mechanics.[33,34] Although it may be too early to suggest that all runners should run at a specific cadence, it is becoming clear that cadence is an important biomechanical running variable, and one that can be easily manipulated in runners when appropriate.

POSTERIOR VIEW

Base of Support

Evaluating the base of support can be an important variable to make note of in specific runners. Running step width can vary as a function of running speed, but may also be related to common running injuries. A general rule can be followed that, when viewed from a posterior video, the left and right feet should not overlap in their ground contact location. It is not necessary that there be a large gap between the foot placement locations of the left and right feet, but there should be some space. A narrow base of support has been linked to tibial stress fractures, iliotibial band syndrome, and several kinematic patterns that have been associated with running injuries, such as excessive hip adduction and overpronation.[35–37] As such, this variable should be evaluated in all runners, and runners with a "cross-over sign" or "scissoring gait," characterized by an overly narrow base of support, may consider modification.

Heel Eversion

Foot pronation in runners is a variable that has received considerable attention over many years.[38–41] However, measuring foot pronation on 2D video presents significant challenges. One component of foot pronation that can be evaluated is heel eversion. By placing markers at the top and bottom of the shoe heel counter (Fig. 10), evaluation of the vertical relationship of the hindfoot can be assessed easily. It is important to evaluate not only the peak magnitude of heel eversion (ie, the relationship of the superior marker to the inferior marker), but also the rate of pronation (Fig. 11). The image in Fig. 11B occurs 5 frames after Fig. 11A, equating to approximately 20 milliseconds (collected at 240 frames per second). This rapid heel eversion is worthy of note as eversion velocity may play a role in specific running injuries. Several studies have linked excessive heel eversion to various running injuries, such as tibial stress fractures, patellofemoral pain, and Achilles tendonopathy.[41–43] Furthermore, it has been suggested that runners with excessive calcaneal eversion be prescribed orthotics,[44] or higher level of support shoes; however, the effectiveness of these strategies has been questioned, and current evidence is inconclusive.[45,46]

Foot Progression Angle

The foot progression angle is the transverse plane position of the foot during stance phase. As a transverse plane variable, it is not easily quantified on 2D video using our suggested setup. However, a general assessment can be made from a posterior video. A typical amount of toe-out observed during running results in the lateral aspect of the shoe being visualized from the posterior view (Fig. 12A). This usually equates to approximately 5° to 10° of toe-out. A mild toe-in abnormality and severe toe-in abnormality are displayed in Fig. 12B, C, and can be identified by the visualization of the 1st ray and medial aspect of the shoe. Abnormally toe-in foot progression angle may be associated with hip internal rotation, knee internal rotation, ankle internal rotation, or some combination of these. Several studies have identified these motions in connection with various running injuries, suggesting that this variable should be considered in a biomechanics running analysis.[47–49] Excessive toe-out is also not uncommonly seen. Although fewer studies have linked excessive toe-out or lower extremity external rotation to running injuries, it is reasonable to speculate that abnormal flexibility, including tight hip external rotators, may play a role in excessive toe-out while running. Further research is need in this area.

Heel Whips

A heel whip is another transverse plane variable that can be challenging to measure accurately on 2D video. However, a recent study has found this metric to be reliably measured from a posterior approach.[50] The whip angle is measured by comparing the angle of the plantar surface of the shoe at initial contact with the plantar surface at the point of maximum rotation (Fig. 13). Although very little has been published on this variable, and the significance of this metric remains unknown, data suggest that an angular rotation of more than 5° in either the medial (see Fig. 13A, B) or lateral (see Fig. 13C, D) is observed in more than one-half of recreational runners.

Knee Window

Excessive hip adduction, excessive hip internal rotation, and excessive knee valgus have all been implicated in running injuries.[3,49,51,52] Each of these variables has the potential to impact the runner's "knee window." Evaluation of the knee window is a simple, dichotomous assessment of the presence or absence of a space between the knees at all times of the running cycle, and is a measure of the alignment of the hip, knee, and ankle from a posterior (or anterior) view (Fig. 14). The knee window does not need to be large—an excessively large knee window may suggest a varus deformity, an alignment issue that also presents with potential problems. However, the vast majority of recreational runners who fail to demonstrate a normal knee window or lose the window during the gait cycle, associated with the kinematic pattern described—namely, excessive hip adduction and internal rotation, and knee valgus. Although identification of this variable is quite simple, it should be noted that correcting an abnormally "closed" knee window is not as simple.[53] There are some limitations to this measurement. It is important for runners to wear shorts or tight-fitting pants so that this variable can be assessed. In runners with excessive soft tissue on the medial aspect of the knee, this measurement can be inaccurate. Finally, swing limb hip adduction can also create the impression of a closed knee window, even in the presence of good hip–knee–ankle alignment. Nonetheless, this measurement can be a valuable component of a biomechanics running evaluation, and several recent studies have found this variable to be modifiable through a variety of methods.[54–56]

Pelvic Drop

Assessing the amount of pelvic drop, or maximum pelvic obliquity during stance phase, can be augmented with the application of markers on the posterior superior iliac spines (Fig. 15). By comparing stance limb and swing limb marker positions, the amount of pelvic drop can be estimated. Excessive pelvic drop during running contributes to excessive hip adduction, a variable that has been linked to numerous running injuries.[49,51] A recent study found that a 2D quantitative assessment of this variable demonstrated excellent reliability but was poorly correlated with a 3D measurement of pelvic drop.[57] However, the clinical significance of 3D-measured pelvic drop has also been called into question.[2,58] It is possible that pelvic drop may serve as a surrogate measure for hip and/or core muscle weakness. Pelvic drop during running has been reported to be significantly related to both hip abductor strength and hip extension strength, and fatiguing of these muscles have been observed to result in excessive pelvic drop.[59,60] Looking for side to side differences can be helpful in detecting excessive pelvic drop and correlation with associated kinetic chain deficits should be performed to see how this contributes to injury. Although further research is necessary in this area, pelvic drop remains as a variable of interest in a biomechanics running analysis.

SUMMARY

Running biomechanics play an important role in the development of injuries in recreationally active individuals. Performing a systematic, video-based running biomechanics analysis rooted in the current evidence on running injuries can allow the clinician to develop a treatment strategy for injured runners. The majority of the current literature has not risen to the level of proven injury prevention strategies in correcting each aspect of running gait detailed in this review, suggesting that recommendations for modification of running form in uninjured runners would not be evidence based. However, when the patient presentation and physical examination findings are in agreement with abnormalities observed in a biomechanics running analysis, it serves as a potential for intervention.

The analysis plan described is not intended to be taken as a "gold standard" or a comprehensive running evaluation. Numerous other running evaluations from a biomechanics perspective are available and should be incorporated into each clinician's protocol.[61,62] It is simply a well-tested and frequently revised evaluation plan that has been successful in evaluating recreational runners. Furthermore, it is expected that this analysis plan will continue to evolve as future research emerges. Certain variables will likely materialize as critical to injury development and prevention, and others will turn out to be unrelated. Nonetheless, the components outlined in this review may serve as a template for a systematic evaluation plan to be improved upon by others, as more information about running biomechanics surfaces. Running biomechanics play a key role in injury development and prevention. Identifying simple 2D surrogates for 3D biomechanic variables of interest will allow for widespread translation of best practices, and have the best opportunity to impact this highly prevalent problem.

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KEY POINTS

- Running biomechanics play an important role in the development of injuries in recreation-ally active individuals.
- Performing a systematic video-based running biomechanics analysis rooted in the current evidence on running injuries can allow the clinician to develop a treatment strategy.
- The current literature has not risen to the level of proven injury prevention, suggesting that recommendations for modification of running form in uninjured runners would not be evidence based.
- When the patient presentation and physical examination findings are in agreement with abnormalities observed in a biomechanics running analysis, it serves as a potential for intervention.

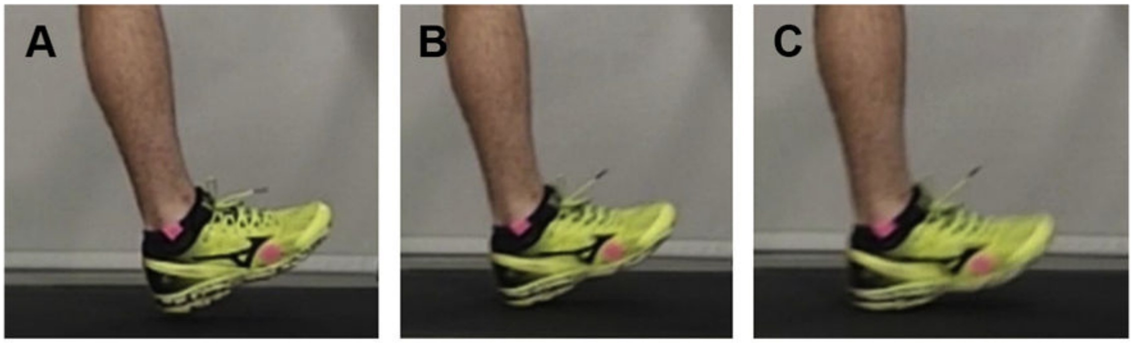

Fig. 1.

Key phases of running. (*A*) The end of terminal swing is identified as to the foot remains elevated from the treadmill, just before initial contact. (*B*) Initial contact is identified as the first frame when the foot hits the ground. (*C*) Loading response is identified as the first frame in which the runner's weight is being transferred onto the lead leg and is characterized by the presence of shoe deformation.

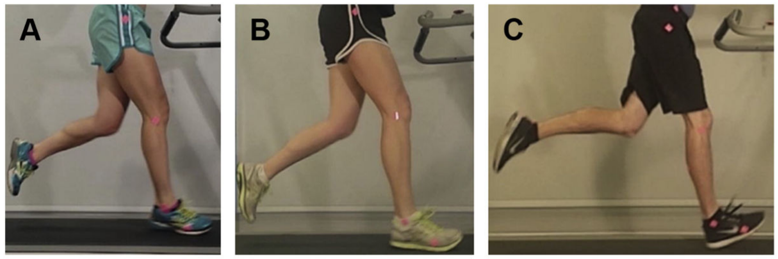

Fig. 2.
Foot strike patterns. (*A*) Forefoot strike. (*B*) Midfoot strike. (*C*) Rear foot strike.

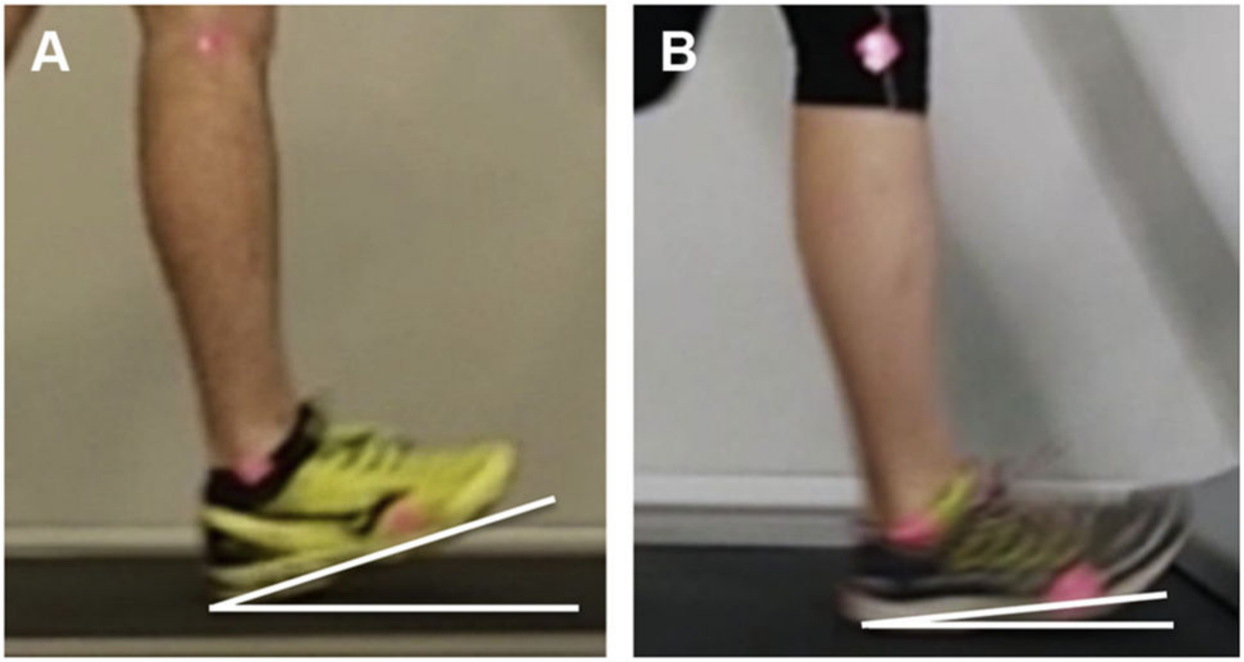

Fig. 3.
Foot inclination angle. (*A*) A relatively high foot inclination angle in comparison with a horizontal line. (*B*) A relatively low foot inclination angle.

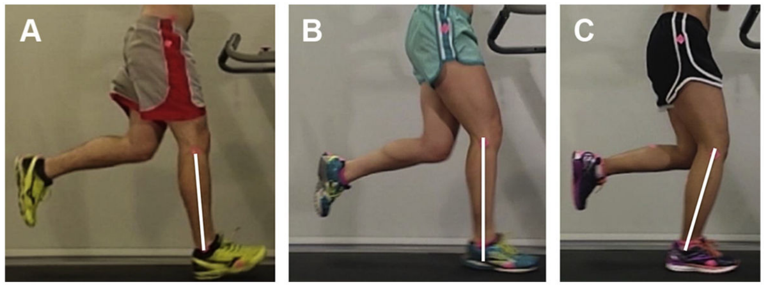

Fig. 4.
Tibia angle. (*A*) Extended tibia. (*B*) Vertical tibia. (*C*) Flexed tibia.

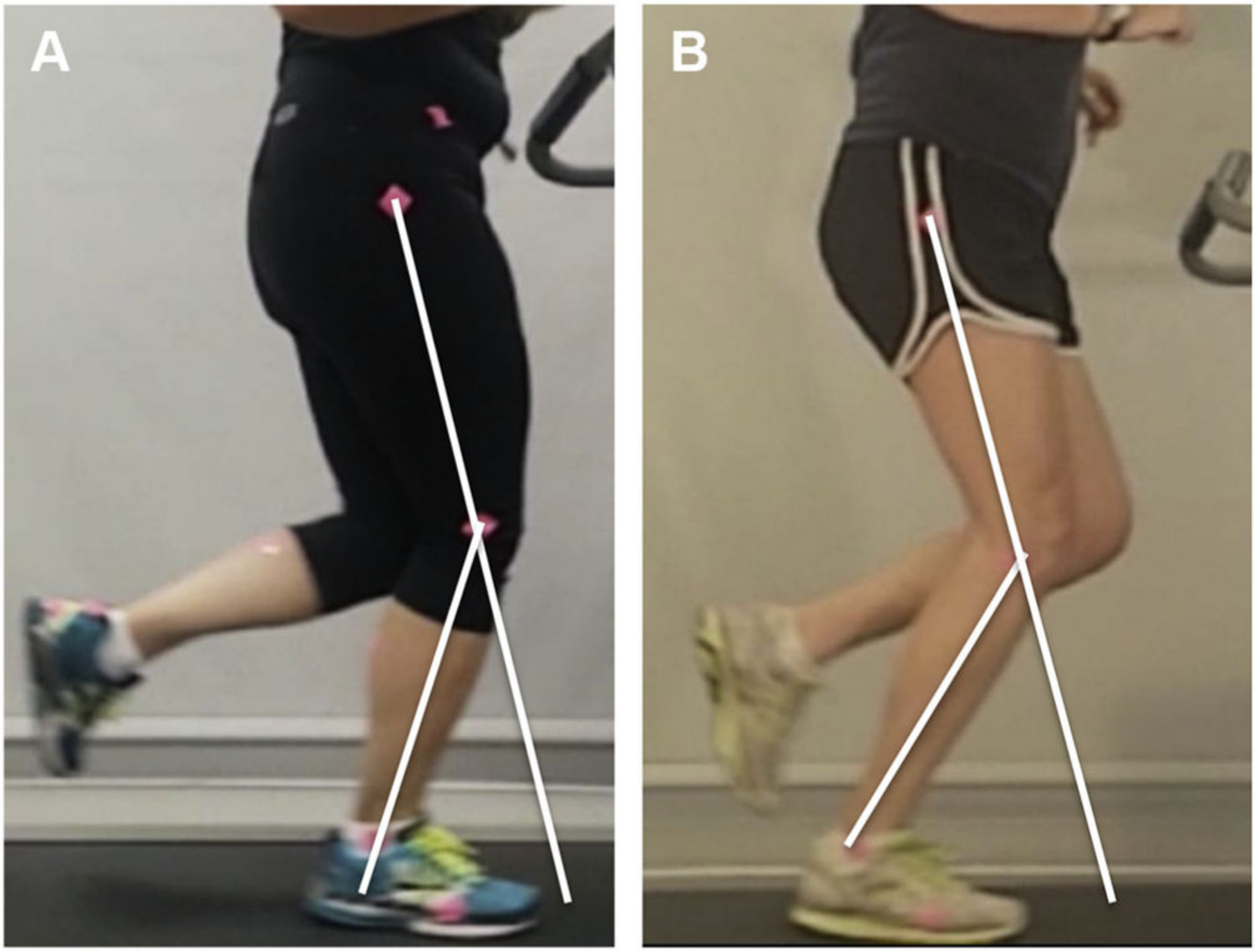

Fig. 5.

Knee flexion during stance. (*A*) A runner demonstrating limited knee flexion during stance and (*B*) a normal amount of knee flexion during stance.

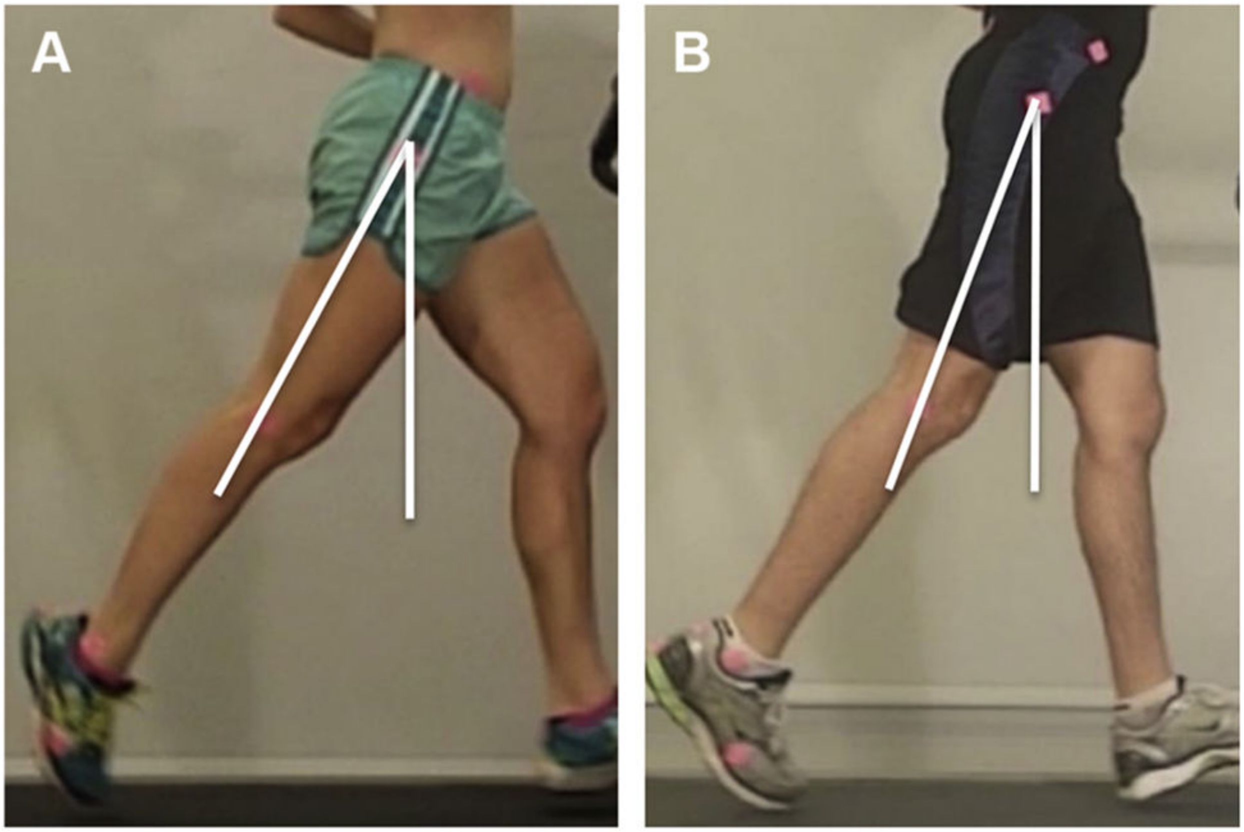

Fig. 6.
Hip extension during late stance. (*A*) Runner with normal hip extension. (*B*) Runner with limited hip extension.

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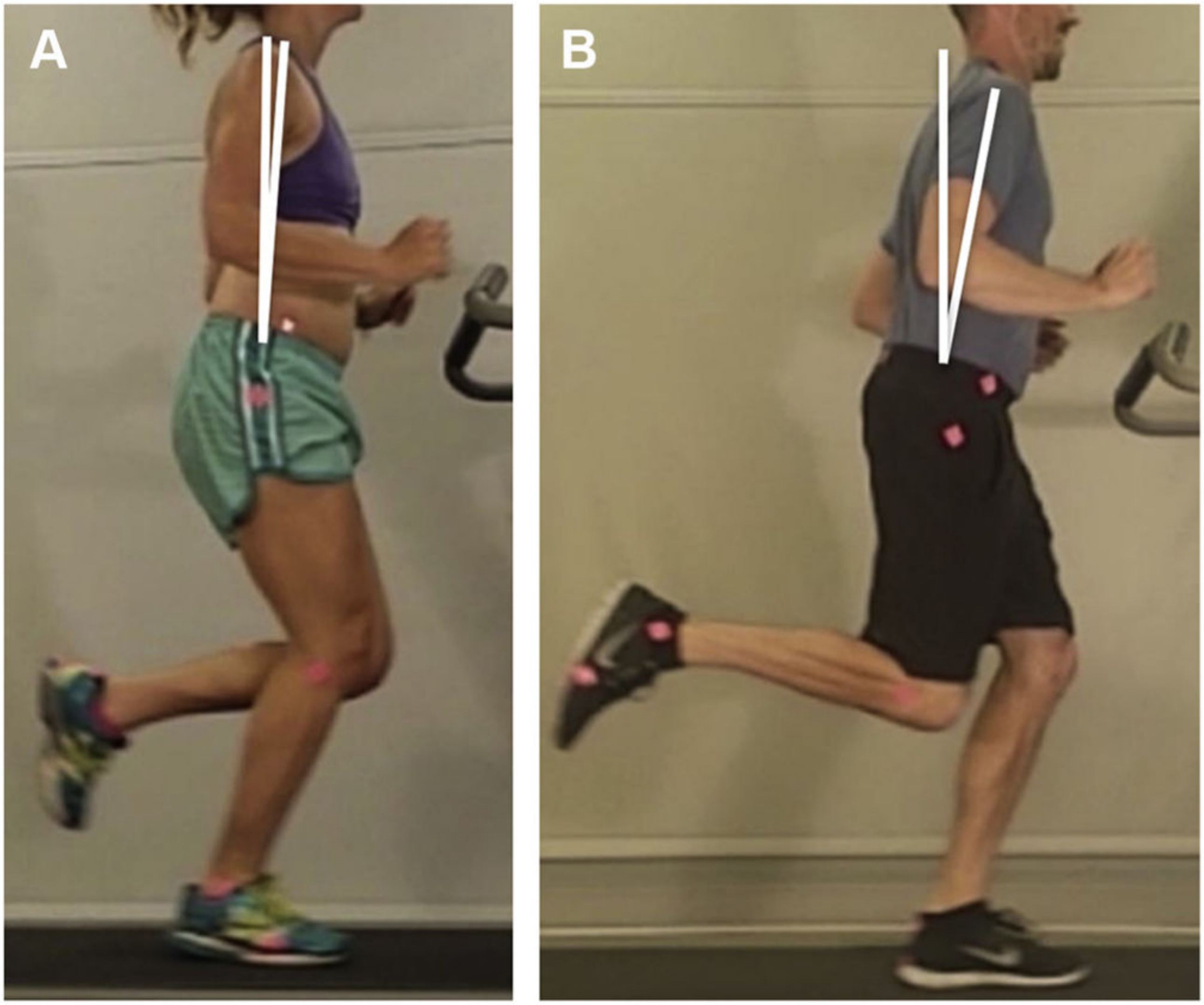

Fig. 7.
Trunk lean. (*A*) A relatively upright trunk posture and (*B*) a runner a forward trunk lean.

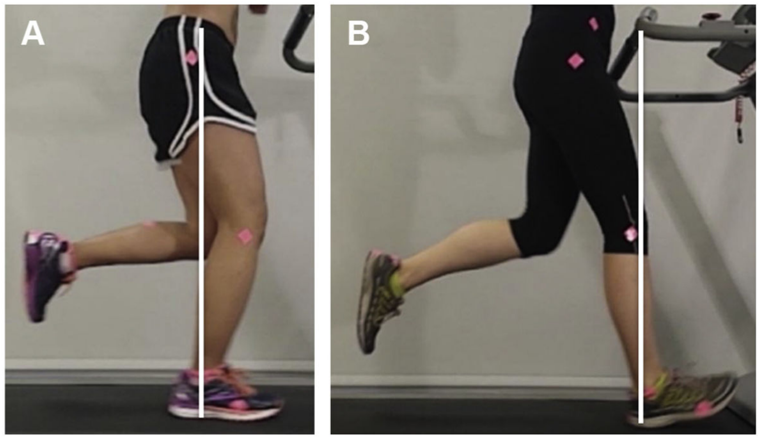

Fig. 8.

Overstriding, measured at loading response. (*A*) A runner demonstrating normal stride mechanics and (*B*) a runner demonstrating an overstride, characterized by a vertical line through the lateral malleolus falling anterior to the runners pelvis.

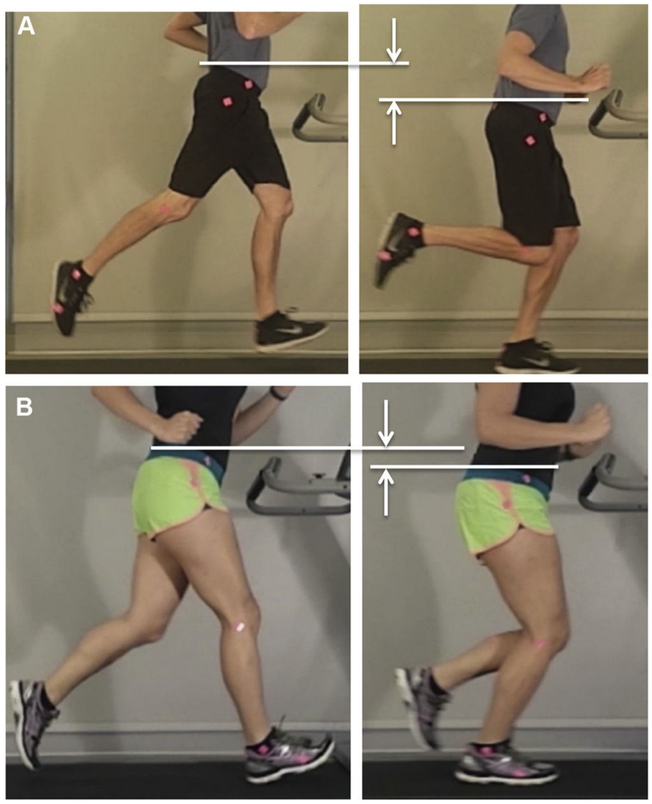

Fig. 9.
Vertical displacement of the center of mass. (*A*) A bounding runner characterized by a large vertical displacement and (*B*) a relatively efficient runner with less vertical displacement.

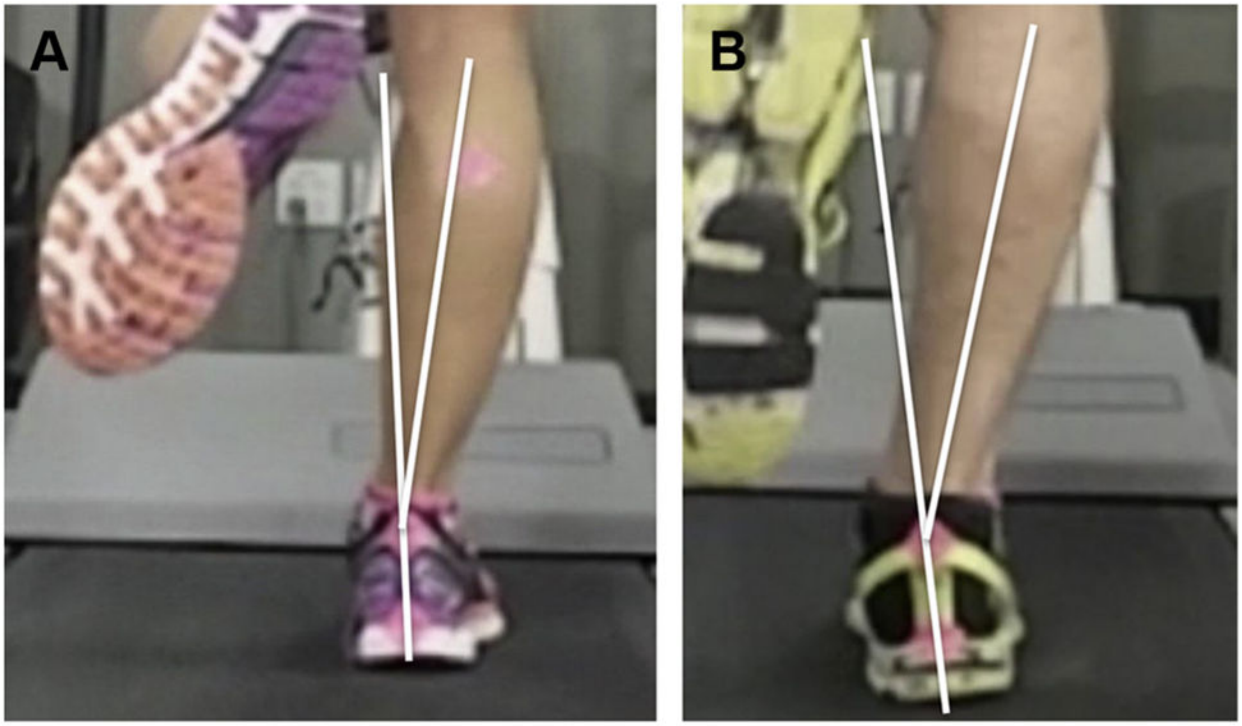

Fig. 10.

Heel eversion. (*A*) A runner with normal alignment of the heel during running and (*B*) a runner with mildly excessive heel eversion during running.

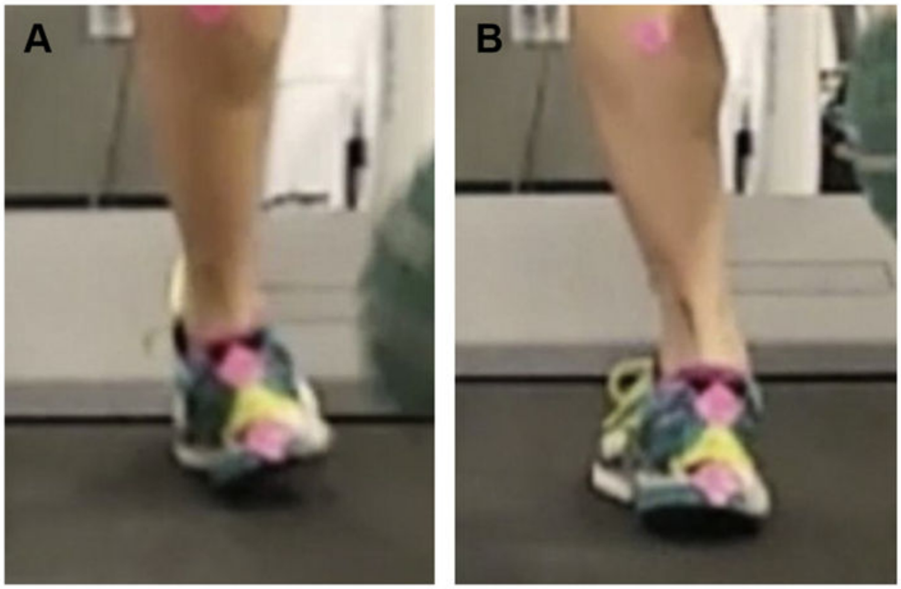

Fig. 11.

Rate of heel eversion. A runner demonstrating excessive heel eversion and a high rate of heel eversion excursion. (*A*) Initial contact with the runner's heel in an inverted position and (*B*) 20 milliseconds later the heel has rotated more than 20° into eversion.

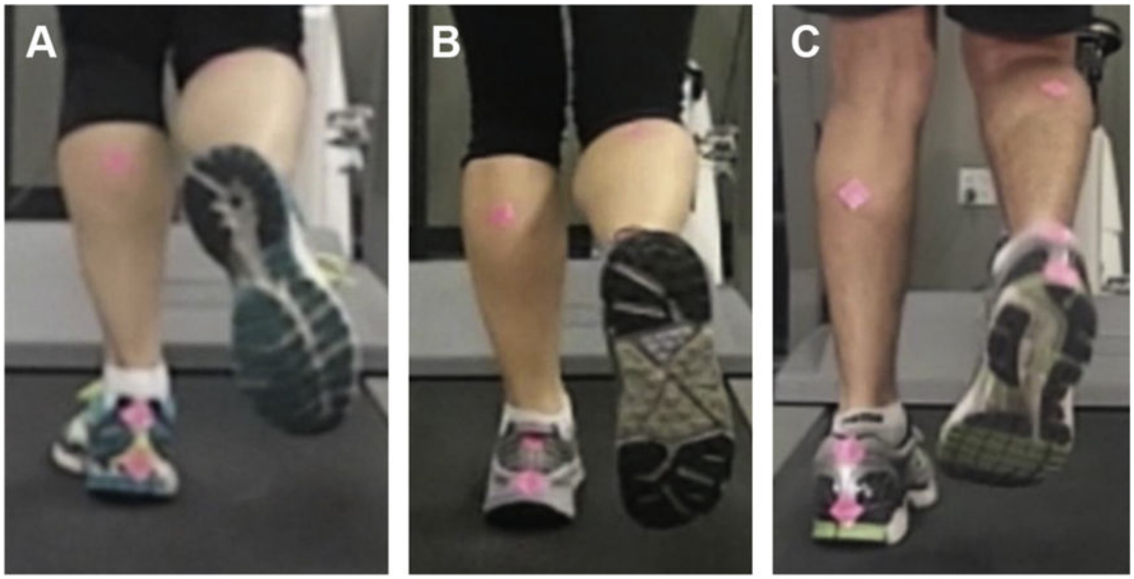

Fig. 12.
Foot progression. (*A*) Normal foot progression angle. (*B*) Mild toe-in abnormality. (*C*) Severe toe-in abnormality.

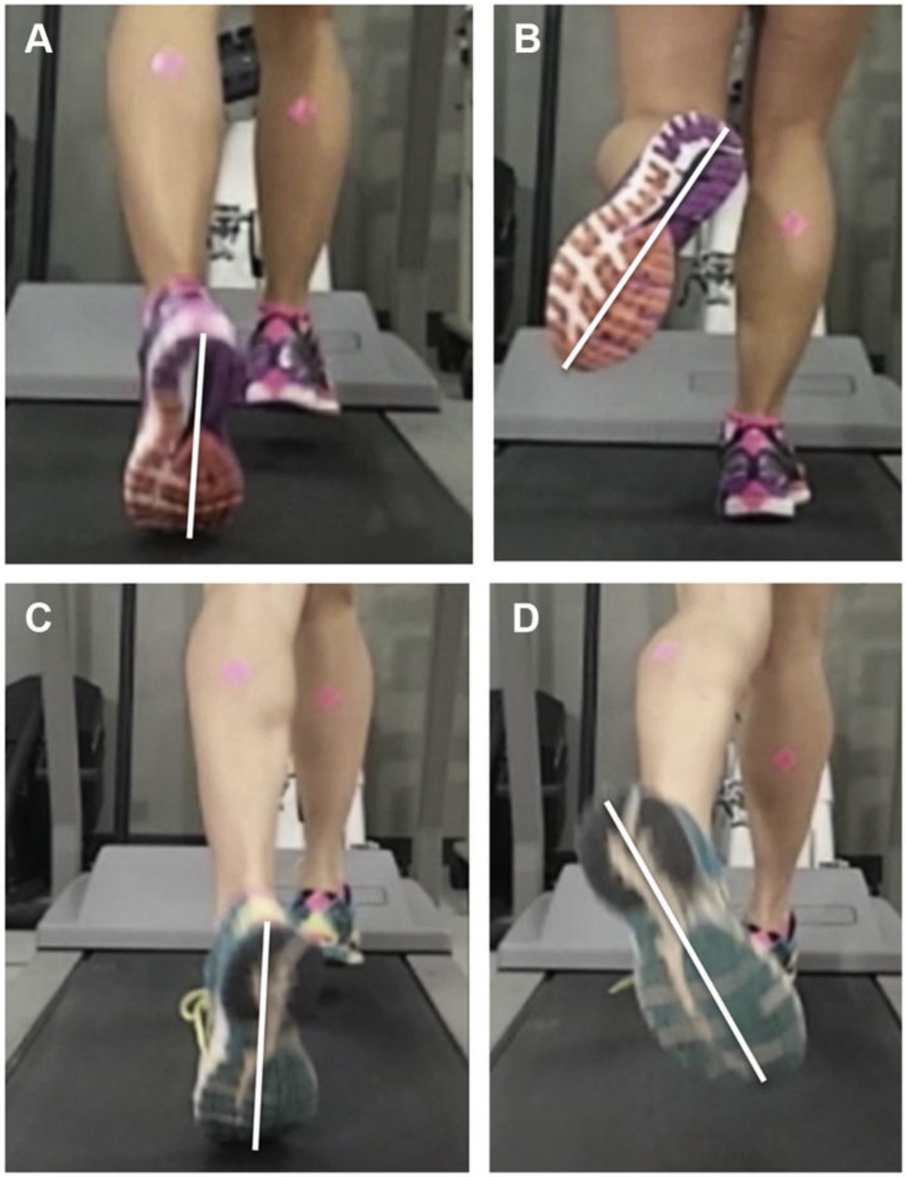

Fig. 13.

Heel whips. Medial heel whip at initial swing (*A*) and maximum whip angle (*B*) and lateral heel whip at initial swing (*C*) and maximum whip (*D*).

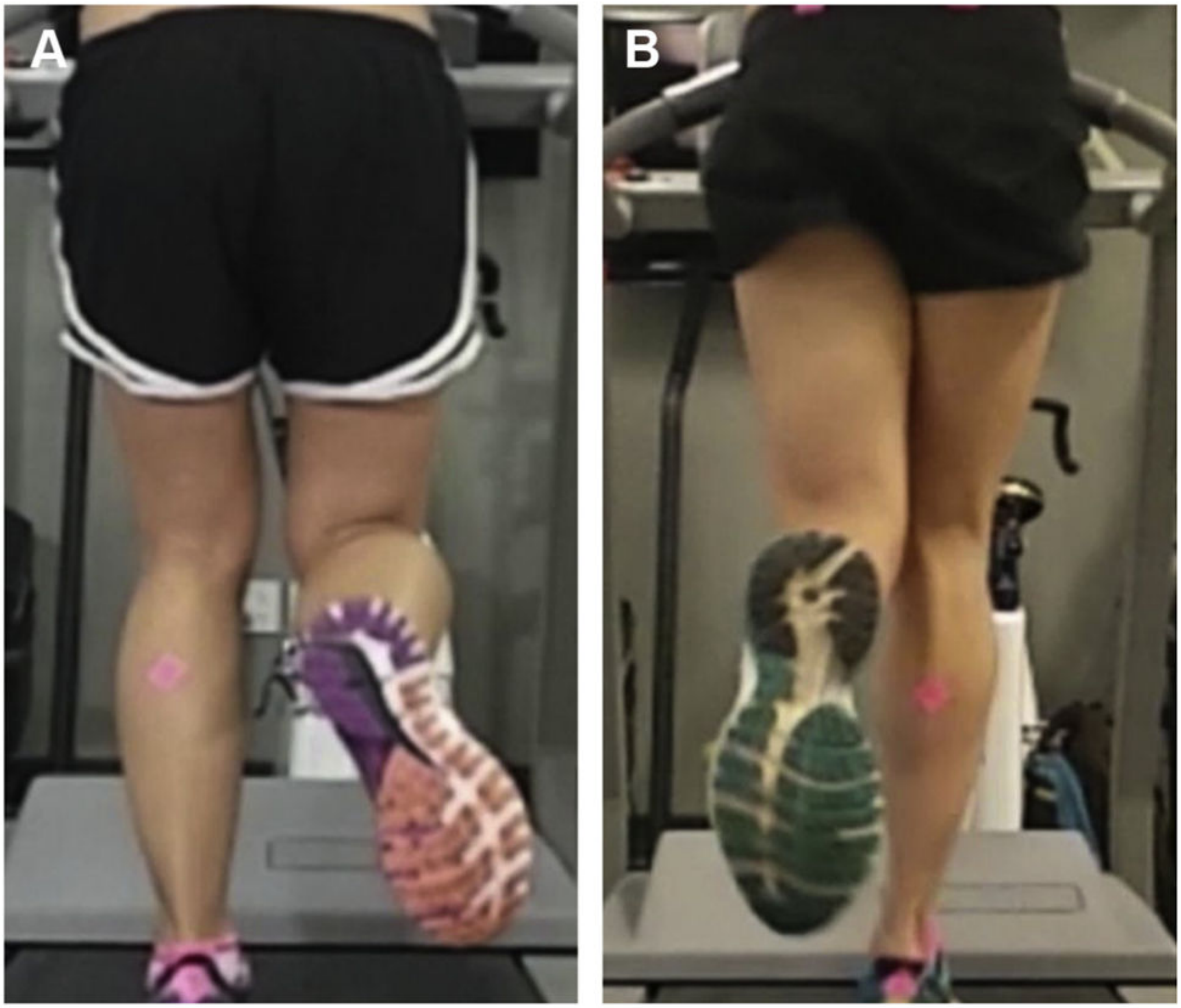

Fig. 14.
Knee window. (*A*) Normal knee window and (*B*) “closed” knee window.

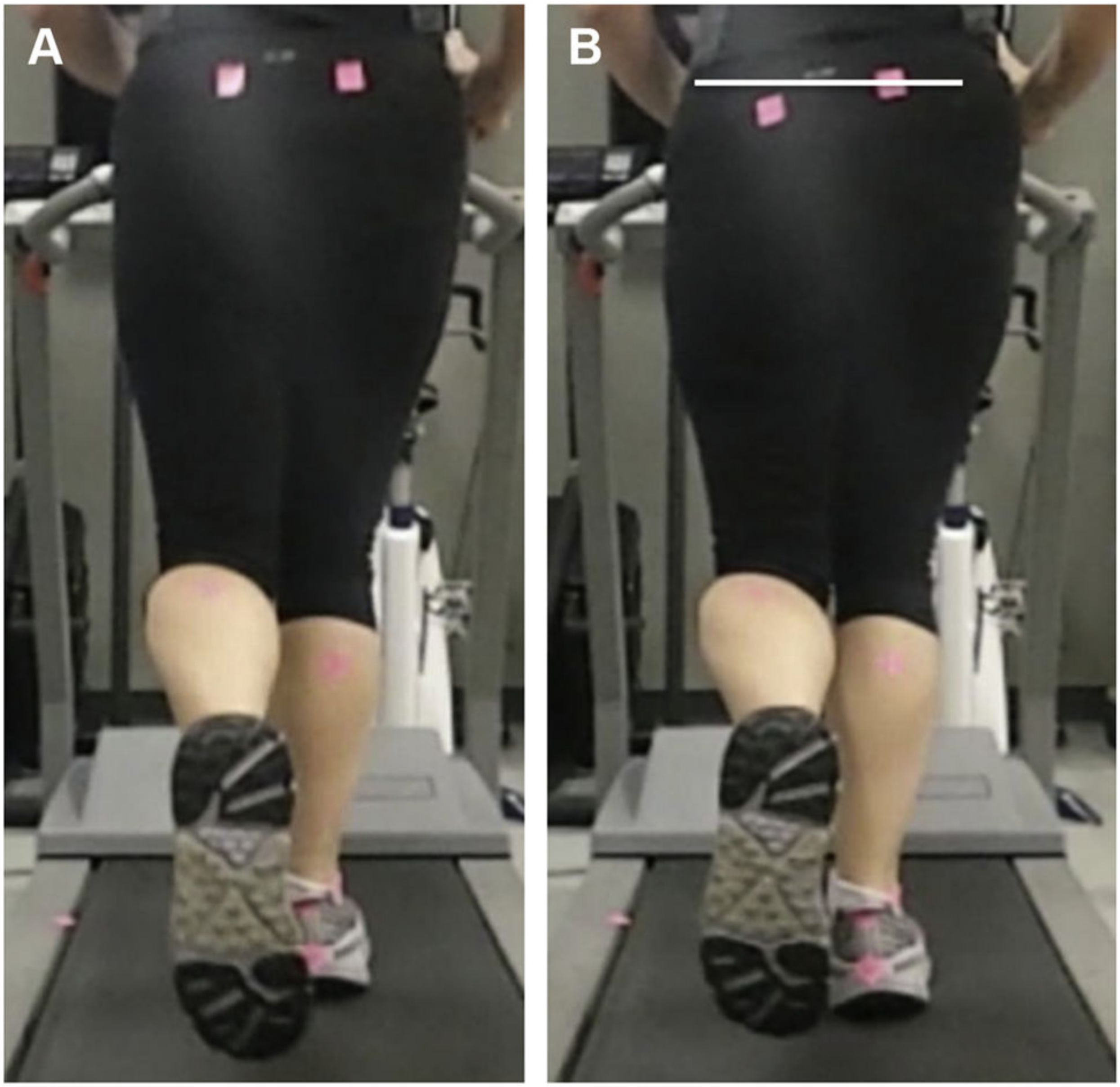

Fig. 15.

Excessive pelvic drop. (*A*) At initial contact the runner's pelvis is fairly level and (*B*) during stance demonstrating excessive pelvis drop.