Impact of Knee Joint Malalignment on Sprint Performance and Injury Risk: Mechanisms and Solutions

Xiaoge Wang *

Beijing Haidian Foreign language Tengfei School, Beijing, 100080, China

* Corresponding Author Email: luchino926494@gmail.com

Abstract. Knee joint displacement, including genu valgus and genu varus, frequently occurs during high-speed running in short-distance races, affecting sprint performance and increasing the risk of injury. These misalignments disrupt the lower limb kinetic chain, leading to inefficient energy transfer and increased stress on the knee and surrounding structures. In addition to impairing forward propulsion, abnormal knee alignment can cause compensatory adjustments in other joints, such as the ankle and hip, which may further compromise stability and performance. The biomechanical mechanisms underlying knee displacement are primarily related to muscular imbalances, where excessive tension in certain muscle groups and weakness in others result in altered joint angles. Effective rehabilitation strategies focus on restoring muscle coordination through targeted strengthening and stretching exercises. Furthermore, corrective interventions such as braces, foot orthotics, and surgical options are explored for individuals with more severe misalignments. This review aims to investigate the biomechanical mechanisms of knee joint displacement and examine the corresponding rehabilitation strategies to improve performance and reduce injury risk.

Keywords: Knee malalignment; genu valgus; genu varus; biomechanics; rehabilitation.

1. Introduction

Malalignment of the knee, such as genu varus and genu valgus, represents a critical biomechanical factor that can impair sprint performance and increase the likelihood of lower-limb injuries. When sprinters are running, they need to ensure that the leg and hip muscles are activated in a coordinated manner, so that the front part of the foot makes contact with the ground at the optimal time, in the optimal position, and with the optimal speed, thereby ensuring the safety and speed of each step [1]. This coordination reflects an efficient lower-limb kinetic chain that enables the smooth transmission of mechanical energy across successive joints. In terms of biomechanics, genu varus and genu valgus play a crucial role in influencing the kinetic chain during sprinting. As an important link in the lower limb kinetic chain, when any point within the chain is defective or interrupted, the efficiency of the kinetic chain will be reduced, which will affect the transmission of energy or force to the distal segments [2]. Both genu varus and genu valgus disturb the normal alignment of the femur and tibia on the coronal plane, altering how muscular forces generated by the iliacus, hamstrings, and quadriceps are transmitted across the knee joint. This force will not only fail to assist the sprinter in moving forward but will also reduce a portion of the forward momentum. Consequently, the athlete experiences reduced mechanical efficiency together with greater lateral stresses on the knee complex.

The abnormal power chain not only fails to conduct the force effectively but also increases the risk of injury to the knee and ankle joints. Displacement of the knee in the coronal plane may induce compensatory adjustments to the ankle, potentially resulting in foot inversion or eversion to maintain body balance. Furthermore, this abnormal force would increase the pressure on one side of the meniscus and also is the major inducement of ACL non-contact injury when the athletes land forcefully [3]. This review aims to clarify the biomechanical mechanisms through which genu varus and valgus affect kinetic chain transmission in sprinters and to identify preventive or corrective strategies that may mitigate their negative effects on both performance and joint health.

2. Mechanisms Underlying Knee Joint Malalignment

From the perspective of kinematics, deviations in knee alignment, commonly manifested as genu valgus and genu varus, are mainly caused by the unbalance of muscles on the inner and outer sides of the thigh. All the muscles on the thigh have their antagonistic muscles, and these two groups of muscles maintain a constant proportion under normal circumstances. Muscles lacking relaxation or lacking strength are two common factors which will cause this muscle to be relatively shorter when compared to its initial length, then lead in abnormal proportion to their antagonistic muscle. Immediately afterwards, the femur, which is controlled by the muscles, will undergo an abnormal displacement relative to the tibia, then cause so-called genu valgus and genu varus [4].

In genu valgus, excessive tension in the medial thigh muscles, including thevastus muscle, sartorius, gracilis, adductor, semimembranosus, and semitendinosus, often results from insufficient post-exercise relaxation or excessive connective tissue proliferation following minor strains. These factors prevent proper muscle relaxation and recovery, increasing muscular tone on the inner side of the thigh. The imbalance is further exacerbated by weakness in the lateral muscle groups, such as the gluteus medius and vastus lateralis, which normally counteract this tension. This imbalance leads to the inward angulation of the knee, resulting in genu valgus. Furthermore, chronic muscle tightness and imbalance not only cause misalignment but also limit the range of motion and flexibility of the affected joints, which can further compromise athletic performance and increase injury susceptibility.

By contrast, the inducements of genu varus are opposite to genu valgus. That is caused by the muscular tension of tensor fasciae latae, iliotibial band, biceps femoris, and vastus lateralis [5]. These muscles become overactive, leading to a shift of the femur inward relative to the tibia. The condition is further compounded by relative weakness in the medial thigh muscles, such as the adductors, which fail to counterbalance the increased lateral force. The result is an outward angulation of the knee joint, or genu varus, which disturbs normal alignment and disrupts the distribution of forces across the knee during dynamic movements. This altered force transmission compromises both the knee's stability and its ability to efficiently transmit energy through the lower limb, which can reduce performance and heighten the risk of injury.

Meanwhile, genu valgus and genu varus can be complication of hip valgus, hip varus, ankle valgus, and ankle varus. Whether the ankle joint or the hip joint rotates inward or outward on the coronal plane, it will cause the knee joint to shift in the opposite direction to a varying degree as a compensatory mechanism. For instance, hip and ankle rotations, either internal or external, can produce compensatory shifts in the knee joint in the opposite direction. This compensatory mechanism is a natural response to preserve the body's center of gravity and balance, but over time it can lead to maladaptive patterns of movement and increased stress on the knee joint. In cases of hip valgus or varus, or ankle malalignment, such misalignments at the distal or proximal joints further compound the malalignment at the knee, exacerbating the overall dysfunction and increasing injury risk.

Athletes with a history of ligamentous injuries, including damage to the lateral collateral ligament, medial collateral ligament and anterior cruciate ligament, are more likely to experience displacement of the knee joint after recovery, but this also depends on the severity of the injury and the state of recovery. The persistence of ligamentous laxity or improper healing of these structures after rehabilitation leaves the knee more prone to instability. This instability may be manifested as recurrent deviations in knee alignment, especially during high-impact or high-load movements, such as sprinting, landing, or cutting. The continued malalignment exacerbates stress on the ligaments and cartilage, leading to a vicious cycle of instability and increased risk for further injury. This dynamic interplay between ligament laxity and misalignment underscores the importance of comprehensive rehabilitation strategies that address both muscular imbalances and joint stability to prevent long-term dysfunction and reinjury.

3. Diagnostic Method for Knee Joint Malalignment

One of the common diagnostic methods for abnormal displacement of the knee on the coronal plane is measuring frontal plane projection angle (FPPA). The diagnosed person needs to do single-leg or step-down test, then calculate the angle formed by two lines. Line 1 is drawn from the anterior superior iliac spine (ASIS) to the midpoint of the tibiofemoral joint. Line 2 is drawn from the midpoint of the tibiofemoral joint to the midpoint of the ankle malleoli on the stance leg. The angle formed on the outer side of the body is measured, and by subtracting this angle from 180 degrees (the straight angle created by Line 1 and its extended line), the resulting angle is obtained. If the calculated angle is greater than 10°, genu valgus is diagnosed; if the angle is less than -10°, genu varus is diagnosed [6]. This method provides a simple yet effective approach to quantify knee malalignment, which is crucial for identifying individuals at risk for injury due to improper knee mechanics.

4. The Effects to Lower Limb Kinetic Chain and Sprinter's Performance

The force exerted by an athlete's sole on the ground creates an opposing force, which travels upward along the tibia and reaches the tibiofemoral joint. Whether it is genu valgus or genu varus, it will cause this force to generate a lateral component. The emergence of this force will reduce the upward force, thereby decreasing the athlete's forward speed. Furthermore, this lateral force can cause instability in the athlete's core or increase the amplitude of their movement during running. In addition, dislocation of the ankle joint and hip joint is an inducement for genu varus and genu valgus, and it can also be a complication. Therefore, the loss of force along the tibia caused by knee displacement often results in further loss at the ankle joint and even the hip joint.

Ankle valgus caused by genu varus always results in flatfoot. This symptom is vital for sprinter. The area where the foot makes contact with the ground has significantly increased. The same force will result in a smaller pressure, thereby reducing the athlete's forward momentum and speed. At the same time, flat feet can lead to a decrease in balance [7]. The balance between the left and right feet is crucial in sprinting, ensuring that each step is forward rather than to the left or right.

5. Potential Injury Risk Associated with Knee Malalignment

The inward or outward bending of the knee joint leads to an increase in the vertical pressure on lateral or medial meniscus. When the knee joint is in motion, such as when acceleration in sprinting, it can also impose additional shear force on the meniscus. In sprinting, an athlete's knee joint has to bear 4 to 8 times the body weight. Therefore, any abnormality in the kinetic chain is highly likely to cause a meniscus tear. One of main functions of medial collateral ligament (MCL) is preventing genu valgus, so inward bending of the knee joint would hurt MCL, which also connect femur and tibia. Even after long-term genu valgus is corrected, MCL laxity can persist as a potential consequence, leading to knee instability and recurring misalignment, as the ligament is unable to effectively stabilize the femur-tibia junction. Similarly, genu varus also may cause lateral collateral ligament (LCL) laxity and following knee instability. When genu valgus occurred, tibiofemoral joint bending inward. The tendon of sartorius and gracilis would be pressed by medial epicondyle of the femur. Prolonged exposure can lead to tendon inflammation and pain and even cause calcification and hardening. In same reason, for genu varus, outward knee would make iliotibial band under pressure, and then result in iliotibial band syndrome, a common overuse injury among runners [8]. The patella is located on the tibiofemoral joint. Excessive unilateral pressure on the femoral head and tibial head can also lead to the maldevelopment of the patella [9]. This developmental abnormality will cause limited knee joint movement and wear on the cartilage at any stage of running. When the ankle joints balancing the abnormal force chain which is caused by genu valgus or genu varus, it might be changed into abnormal angle too. Genu valgus might result in ankle varus. Patients are more likely to get injury with anterior talofibular ligament (ATFL), which is mainly caused by sprain of ankle. Genu varus might cause knee valgus or flat foot, that is a main inducement of injury of tibionavicular ligament, tibiospring ligament and tibiocalcaneal ligament.

6. Correction Strategies for Knee Joint Malalignment

Genu valgus and genu varus involve abnormal positioning of the femur and tibia, often resulting from imbalances in the surrounding muscle groups. To address these malalignments, interventions typically focus on restoring muscle coordination. This can be achieved by stretching overactive muscles to release tension and promote elongation, while simultaneously strengthening underactive muscles to improve their pulling force. The key to effective correction lies in re-establishing the balance between the medial and lateral muscle groups around the femur, which is essential for restoring proper joint alignment. In certain cases, particularly for younger athletes with incomplete skeletal development, corrective braces may be used to support the joint during physical activity. Additionally, incorporating footwear with a higher heel on the affected side during exercise can alleviate the instability caused by knee misalignment by adjusting the body's posture.

For adolescents with undeveloped epiphyseal lines, epiphyseodesis is often employed as a non-invasive alternative to osteotomy. This technique involves restricting the growth of the epiphyseal plate on the misaligned side, allowing the opposite side to continue its growth. This gradual correction of the joint alignment avoids the need for surgical intervention while facilitating bone development in a more optimal direction. For adults whose bones have fully matured, surgical interventions such as High Tibial Osteotomy (HTO) or Distal Femoral Osteotomy (DFO) are considered. These procedures involve surgically modifying the tibia or femur, respectively, to adjust the alignment of the knee. Following recovery, the bones heal in a more anatomically correct position, thereby restoring proper knee function and reducing the risk of further complications.

7. Conclusion

Knee misalignments, especially genu valgum and genu varum, have a significant biomechanical impact on sprinters. These misalignments disrupt the efficiency of the lower limb kinetic chain, affecting energy transfer and increasing injury risk. Rehabilitation strategies targeting muscle imbalances, such as strengthening weak muscles and stretching overactive muscles, can help restore proper joint alignment and reduce negative impacts on athletic performance. While these interventions are beneficial, current approaches remain somewhat general and may not adequately address individual differences in response. Treatment plans must consider factors such as age, training level, and specific biomechanical characteristics. Personalized rehabilitation programs that take these factors into account are more likely to achieve better results. Future research should focus on refining treatment plans by integrating real-time biomechanical feedback and personalized training programs. Advances in motion analytics, particularly AI-assisted tools, can provide more precise data revealing how different interventions affect athletes with varying biomechanical characteristics. Long-term studies are needed to validate the effectiveness of these personalized strategies in preventing injury and improving athletic performance.

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