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Investigating the Impact of Unilateral Wedge-Induced Foot Pronation on Lumbar Spinal Alignment: A Correlational Analysis

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Abstract: *This study investigates the relationship between foot misalignments induced by wedges and lumbar spinal alignment, with a specific focus on the frontal plane, aiming to shed light on potential factors contributing to low back pain, a leading cause of disability. Screening 68 volunteers, the research selected 35 subjects using random sampling and performed measurements involving the navicular drop test, calcaneal eversion and inversion, Passive Accessory Intervertebral Motion (PAIVM) assessment, and limb length examination. Results showed significant changes in Navicular height across all testing positions, while spinal deviation remained insignificantly altered. Although no direct correlation between Navicular height and Spinal Deviation was observed, the study highlights the potential for foot pathologies to induce postural adaptations and lumbar instability, emphasizing the need for further exploration of this intricate biomechanical relationship in the context of low back pain prevention and treatment.*

IndexTerms - Pronation, Spine, Deviation, Back Pain

I. INTRODUCTION

The human body operates within a dynamic interplay of movement and postural patterns, engaging all its systems to facilitate various activities. Every action stems from the intricate coordination of bodily functions, with even fundamental processes such as circulation, respiration, and digestion relying on the well-functioning locomotor system. Comprising muscles, bones, and joints, the locomotor system serves as the foundation for both stability and mobility. Guided by mechanical principles, the behavior of the spinal column and the locomotor system at large adheres to specific patterns under strain, subsequently leading to adaptations throughout the body. A pivotal role of the locomotor system is maintaining equilibrium, a task accomplished through the assimilation of sensory input from diverse receptors spanning the entire body. Alongside equilibrium organs, proprioceptors present in muscles, tendons, fascia, and joints assume a vital role. Notably, the spinal column's curvature significantly contributes to its stability, implying that vertebrae work in concert to position the spinal column strategically under strain, thereby countering pressure through inherent curves. When strain is imbalanced, an asymmetrical scenario arises, potentially manifesting as a scoliotic posture. [1]

The human body operates holistically, functioning as a cohesive entity. Previous research indicates a correlation between alterations in foot alignment and corresponding changes in pelvic alignment. However, scant data exists connecting foot misalignments, particularly in the frontal plane, to spinal adjustments. Positioned centrally within the body, the pelvis serves as a pivotal linkage between lower limb movements and spinal segmental motions. This functional kinematic chain plays a crucial role in transmitting loads both proximally and distally. Consequently, the mechanics of the lumbar region, pelvis, and lower extremities are interdependent. [2]

The context of unilateral weight-bearing is a prevalent factor in numerous daily functional tasks. Within this framework, the impact of the kinematic chain originating from the foot may wield a more pronounced influence on proximal segments during unilateral weight-bearing compared to bilateral weight-bearing situations. The alignment of the hindfoot substantially affects the movement of adjacent bones and joints in weight-bearing stances. [2]

Chronic lower back pain stands as a prominent contributor to long-term disability. Despite the adoption of various symptomatic treatments, the root of the issue might rest within the evaluation process itself. Subtle alterations in foot alignment can potentially pave the way for subsequent back problems. Given the human body's mechanical analogy to a lever, even minor biomechanical adjustments can trigger a cascade of changes. While it's not unexpected that irregular foot biomechanics could lead to spinal complications, the sheer range of conditions associated with excessive pronation is noteworthy. These encompass a spectrum from Calcaneal periostitis and Navicular stress fractures to Achilles tendinitis, Fibula stress fractures, Patellofemoral pain syndrome, Anterior Pelvic Tilt, and Functional Scoliosis. The interplay of diverse mechanical factors profoundly influences shifts in bodily posture. [2]

Leg length discrepancies resulting from abnormal foot alignment lead to biomechanical changes, including ilium rotation backward on the longer leg side and forward on the shorter leg side. The iliac crest elevates on the longer leg side, while the entire pelvis tilts and rotates toward the longer leg. The sacral base tilts toward the shorter leg, increasing LSC lordosis, particularly at the LSJ. The shoulder lowers on the longer leg side, unless the discrepancy is substantial. The head tilts toward the shorter leg, and pelvic translation occurs toward the longer leg, expanding the lumbar triangle on the shorter leg side. These alterations highlight the interconnectedness of foot alignment and pelvic and spinal positioning, underscoring the potential for foot-related factors to influence overall postural dynamics. [1]

In situations of bilateral weight-bearing, pelvic alignment can be influenced by the movements of both legs. However, the specific impact of calcaneal eversion on pelvic kinematics in three dimensions remains unexplored during unilateral weight-bearing scenarios, such as standing on a single leg. Consequently, there exists a knowledge gap regarding the direct ramifications of calcaneal eversion on pelvic motion under these conditions. Hence, it becomes imperative to scrutinize the correlation between calcaneal eversion and the alignment of the proximal segment in instances of unilateral weight-bearing. [2]

The alignment and mobility of the lumbopelvic complex rely on the osteoligamentary system's integrity, muscular-fascial interactions, and effective neuromuscular control. Proper pelvic alignment is crucial for mechanical efficiency, optimizing performance, preventing injuries in sports, exercise, and daily tasks. The pelvis can be likened to a balanced 'see-saw' atop the hip joints. Imbalances within pelvic structures can trigger a chain reaction of postural compensations along the axial spine, increasing vulnerability to recurring issues, diminished function, and deformities. Pelvic positioning is influenced by factors like alignment of lower limb joints during closed kinematic chain activities. For instance, lower limb length discrepancies induce lateral pelvic tilt, potentially causing lumbar spine pathologies. Altered lower limb posture can lead to lumbopelvic complex postural changes, heightening the risk of low back pain development.

Our body comprises three 'Hinge zones': the Occipitoatlantoaxial complex, Lumbosacral joint, and the Foot. These zones experience weight redistribution across three planes: sagittal, frontal, and horizontal, respectively. Notably, a study demonstrated that individuals with persistent low back pain, despite traditional treatment, experienced a substantial 70% improvement in symptoms through leveling the sacral base using shoe inserts. Common malpositions encompass flat foot (pes planus), valgus of the rear foot (pes valgus), pes abductus, and lateral inclination of the sacral base. Consequently, this study aims to quantify the impact of wedge-induced foot pronation on lumbar spinal alignment and establish a correlation between Navicular height and lumbar spinal alignment.

II NEED OF THE STUDY.

The significance of this study lies in addressing the intricate connection between unilateral pronated foot conditions and lumbar alignment. With the prevalence of low back pain as a leading cause of disability, investigating the potential link between foot alignment and lumbar spinal posture becomes crucial. Understanding how biomechanical alterations in foot alignment can influence pelvic and lumbar alignment could provide valuable insights into preventive measures and therapeutic interventions for individuals at risk of developing low back pain. By exploring the effects of calcaneal eversion under unilateral weight-bearing conditions, this study aims to bridge the knowledge gap surrounding this relationship. The findings could lead to improved strategies for assessing and managing individuals with foot misalignments, potentially reducing the risk of postural compensations, dysfunction, and debilitating conditions in the lumbopelvic region.

III RESEARCH METHODOLOGY

3.1Population and Sample

This investigation constitutes a Prospective Experimental study that explores the link between unilateral pronated foot and lumbar alignment. The subjects were included with age 18-25 years, displaying normal calcaneal eversion and inversion, with a navicular drop height of 6-10mm [5], BMI between 19-25, and normal PAIVM [6]. The subjects were excluded in case of ankle, leg, or back pain, musculoskeletal injuries, recent ligament issues, limb length discrepancy >1cm, unilateral pelvic tilt, or scoliosis.

3.2 Data and Sources of Data

The research was executed at the Research Laboratory of the Department of Physiotherapy, SBSPGI, Balawala, in addition to Mata Gujri Girls Hostel, SBSPGI, Balawala, Dehradun. A preliminary pilot study was conducted with a cohort of five individuals, drawn from the available population. Building upon insights from the pilot study, the main investigation was carried out with a sample size of 35 subjects meeting clinical evaluation and eligibility criteria. These participants, aged between 18 and 25 years (with an average age of 21.62), were students at SBSPGI, Balawala, Dehradun. Subjects for the study were randomly selected through a lottery-based simple random sampling technique.

3.3 Theoretical framework

Dependent Variables studied were lumbar alignment using Passive Accessory Intervertebral Motion (PAIVM) and navicular height using Navicular Drop Test and Independent variables studied were Foot pronation. The instrumentation utilized was measuring tape, ruler, goniometer for measurements, platform wedges to induce foot pronation, digital camera with tripod stand for standardized photography, ensuring accurate data collection and assessment.

Determining the navicular drop involves measuring the height variance of the navicular tuberosity from the floor. This measurement is taken while the individual is in a sitting position, with the subtalar joint in a neutral state, and during a relaxed stance.

Conducting the central postero-anterior Passive Accessory Intervertebral Motion (PAIVM) test aims to identify subjects with hypermobile or hypomobile vertebrae for exclusion. The patient assumes a prone position, with the hypothenar eminence making contact with the target vertebra's spinous process. Gradually, a posteroanterior force is applied. Each lumbar vertebra undergoes assessment, classified into grades 0, 1, and 2 to signify hypomobility, neutral mobility, and hypermobility respectively. Participants with a Grade-0 classification are eligible for inclusion in the study. [7]

3.4Statistical tools and econometric models

This section elaborates the proper statistical tools which were used to forward the study from data towards inferences. The acquired data underwent analysis utilizing SPSS version 16 software. To examine the correlation between spinal deviation and Navicular height at neutral, 10-degree wedge-induced pronation, and 20-degree wedge-induced pronation, the Karl Pearson Correlation formula was employed. Additionally, the data was further assessed using One-Way ANOVA to ascertain the scientific connection between spinal deviations and Navicular Height across all three testing positions.

The detail of methodology is given as follows.

3.4 Procedure and Protocol

The research protocol involved screening subjects to determine eligibility, consisting of the navicular drop test, calcaneal inversion and eversion range of motion assessment, limb length measurement, and passive accessory intervertebral motion assessment.

To commence, demographic data encompassing age, height, weight, etc., were collected from each participant. A subjective assessment was conducted to identify symptoms, pain presence, history of trauma, surgeries, and medical illnesses. The navicular drop test was performed by gauging the height difference of the navicular tuberosity from the floor while sitting with the subtalar joint in a neutral position and during relaxed stance. Subjects were seated with feet flat on a solid surface, unweighted, knees flexed to 90 degrees, and ankle joint in neutral position.

To execute the navicular drop test:

- The navicular tuberosity was palpated approximately one and a half inches anteromedially from the medial malleolus.
- The most prominent point of the navicular tubercle was identified and marked while maintaining subtalar neutral position.
- An index card was placed vertically on the inner hindfoot, passing the navicular bone. The level of the navicular tubercle's most prominent point was marked.
- Subjects stood without altering their foot position, distributing equal weight on both feet. The most prominent point's level was marked again.
- The disparity between the initial sitting position and weight-bearing positions was measured using a tape measure, providing the navicular drop measurement.

For assessing passive accessory intervertebral motion, the central poster anterior PAIVM test was employed. It aimed to exclude subjects with hypermobile or hypomobile vertebrae. Subjects lay prone, with the Hypothenar eminence contacting the target vertebra's spinous process. Gradual posteroanterior force was applied, evaluating each lumbar vertebra on a scale of 0 (hypomobility), 1 (neutral), and 2 (hypermobility). Grade-0 subjects were included.

To gauge calcaneal inversion and eversion, subjects adopted a prone position with stabilized tibia and fibula to prevent hip and knee movements. The goniometer's fulcrum centered on the ankle's posterior aspect, aligned with proximal and distal arms. The foot was taken through inversion and then returned to neutral, followed by eversion. Goniometric readings were noted for both motions.

From an initial group of 57 subjects meeting criteria, a subset of 35 was randomly selected using Lottery system. Subjects were instructed to stand in a relaxed stance upon arrival. Marks were made at each Posterior Superior Iliac Spine (PSIS) using Venus dimples as reference points. Lumbar spinous processes were palpated to mark L5, L4, L3, L2, and L1, and subjects stood 25 cm from the camera for subsequent analysis.

The protocol progressed through several steps:

1. Photographs were taken with focus on L3 as subjects stood in relaxed stance.
2. A 10-degree wedge was placed under the right foot with pronation induced, followed by re-marking of PSISs and lumbar spinous processes.
3. The above procedure was repeated using a 20-degree wedge.
4. Corel Draw Image Tool was employed to analyze all three photographs.
5. Pelvic tilt angle was determined by drawing a line connecting the left and right PSIS marks and measuring the angle.
6. An angle was measured from L1 to a line perpendicular to the "normal" of the PSIS.
7. Navicular heights were measured and tabulated for each of the three photographs.

In essence, this study's methodology encompassed subject screening, data collection, various assessments, and subsequent analysis of photographs using Corel Draw Image Tool to measure angles and tabulate navicular heights. This comprehensive approach aimed to quantify the relationship between wedge-induced foot pronation and lumbar spinal alignment.

INSTRUMENT VALIDITY:

- Wedged- Platform: $r = 0.612–0.945$, $p < 0.0001$ [5]
- Navicular Drop Test: Navicular drop test indicated moderate to good reliability, with ICC of 0.78 and 0.88 for right and left knee, respectively [6]
- Calcaneal Eversion And Inversion: ICC range: .81-.94 [9]

IV. RESULTS AND DISCUSSION

4.1 Results of Descriptive Statics of Study Variables

Karl Pearson Correlation Coefficient:

A notable alteration was evident in Navicular height across all three testing positions (p=0.0107). Conversely, spinal deviation exhibited insignificant change in all three testing positions (p=0.2349). Evaluation of the correlation between spinal deviation and navicular height utilized the Karl Pearson Correlation Coefficient within SPSS software version 16.

Table 4.1 showing the Correlation between Spinal Normal Weight Bearing vs. Navicular Height Normal Weight Bearing (p- value 0.623), Spinal Normal Weight Bearing vs. Navicular Height 10 degree (p- value 0.523), Spinal Normal Weight Bearing vs. Navicular height 20 degree weight bearing (p- value 0.528), Spinal 10 degree weight bearing vs. Navicular height normal weight bearing (p- value 0.773), Spinal 10 degree weight bearing vs. Navicular height 10 degree weight bearing (p- value 0.904), Spinal 10 degree weight bearing vs. Navicular height 20 degree weight bearing (p- value 0.953), Spinal 20 degree weight bearing vs. Navicular height Normal weight bearing (p- value0.505), Spinal 20 degree weight bearing vs. Navicular height 20 degree weight bearing (p- value 0.608).

VARIABLES	**p- value**
SNWB vs. NHNWB	0.1665
SNWB vs. NH10	0.1456
SNWB vs. NH20	0.1322
S10 vs. NHNWB	0.1840
S10 vs. NH10	0.1645
S10 vs. NH20	0.1613
S20 vs. NHNWB	0.0718
S20 vs. NH10	0.0605
S20 vs. NH20	0.0751

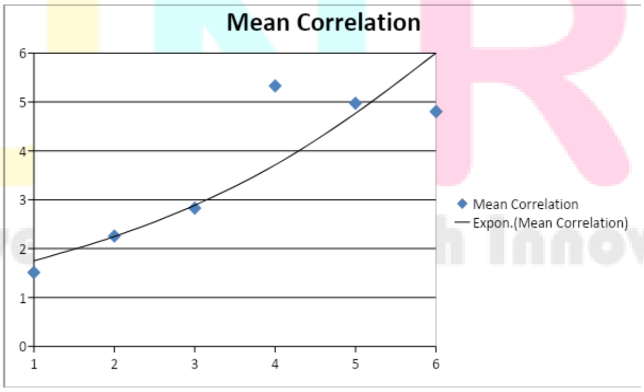
Table 4.2 showing the significance of Spinal Deviation and Navicular height change using ANOVA test and tallied by Microsoft Excel version 2007ANOVA calculator (significant at p value=0.0107)

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.985333	2	2.492667	4.745531	0.0107	3.085465
Within Groups	53.57714	102	0.525266			
Total	58.56248	104				

Table 4.3 ANOVA test for Spinal deviation are significant (significant at p value= 0.000186)

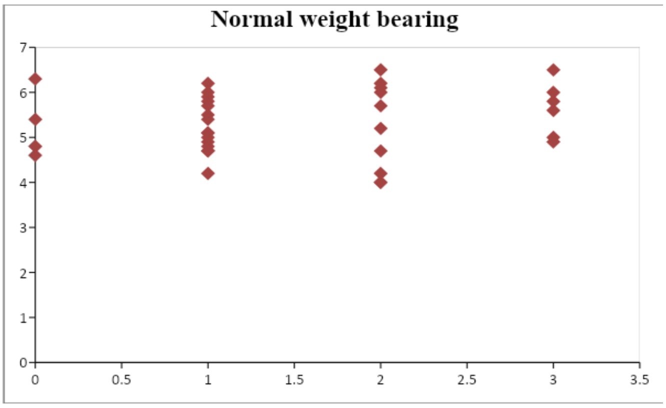
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	29.04762	2	14.52381	9.355828	0.000186	3.085465
Within Groups	158.3429	102	1.552381			
Total	187.3905	104				

Graph 4.1 Showing mean correlation between Navicular height and Spinal deviation

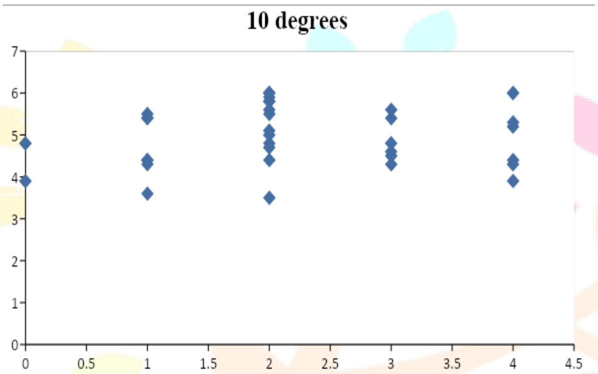


:

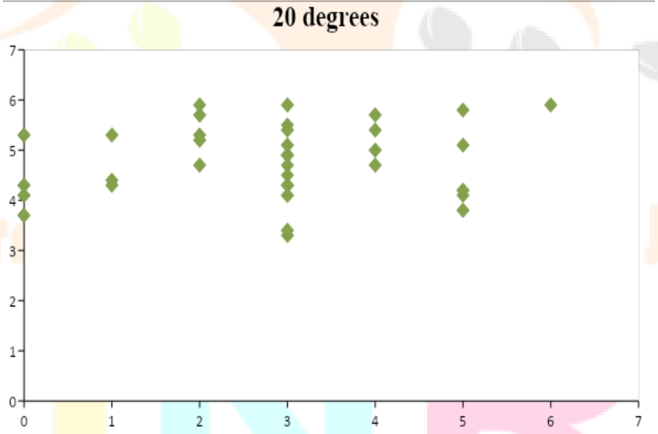
Graph 4.2 Showing Correlation between Navicular height (Y-axis) and Spinal deviation (X- axis) at normal weight bearing:



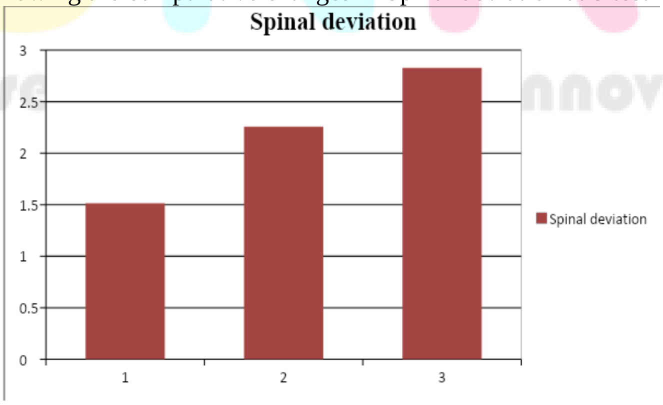
Graph 4.3 Showing Correlation between Navicular height (Y-axis) and Spinal deviation (X-axis) at 10 degrees wedging



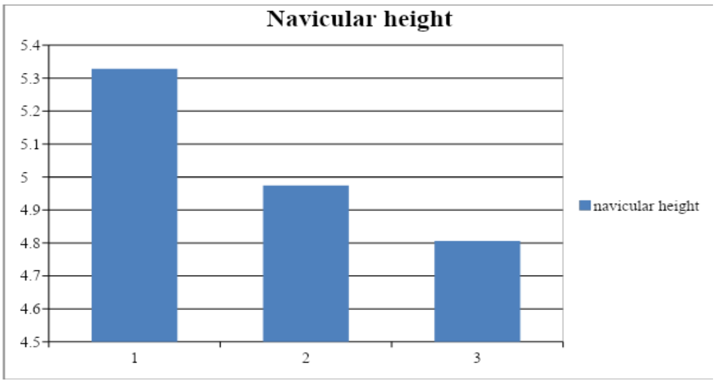
Graph4.4 Showing Correlation between Navicular height (Y-axis) and Spinal deviation (X-axis) at 20 degrees wedging



Graph 4.5 Showing the comparative changes in Spinal deviation at 3 testing positions:



Graph 4.6 Showing the comparative changes in Navicular Height at 3 testing positions



Correlation between Navicular Height and Lumbar Spinal Alignment:

Upon a comprehensive examination of the data using the Karl Pearson Correlation Coefficient (r-values of 0.142569, 0.145698, and 0.161345 for Normal weight bearing, 10 degrees, and 20 degrees, respectively), it was evident that there exists no statistically significant correlation between Navicular height (utilized as an indicator of Foot pronation) and Lumbar spinal alignment in all three testing positions (Normal weight bearing, 10-degree wedging, and 20-degree wedging), with p-values exceeding 0.05. The scatter plots generated following the analysis also depict a lack of statistically significant correlation between these variables. This suggests that no substantial positive or negative correlation exists between these variables regarding changes induced by foot pronation. This phenomenon can be elucidated by the fact that the changes in the segments brought about by the wedge's influence instigate postural adaptations to counteract the altered center of gravity, consequently prompting increased muscle activation to maintain stability. Moreover, the spinal column, composed of multiple segments, undergoes minute adaptations at the segmental level mediated by proprioceptors, potentially varying across different spinal segments. Consequently, the correlation observed between the spinal column as a whole and navicular drop did not yield a statistically significant result. The immediate dynamic changes recorded in this study, although noteworthy, were not substantial enough to establish a definitive correlation. However, it should be noted that in cases of prolonged exposure, individuals with foot pathologies may adapt their posture to accommodate underlying foot deformities. [2]

Nevertheless, previous research has consistently reported that in prolonged instances, the foot can significantly influence the pelvis. Calcaneal eversion, for instance, induces medial rotation of the lower extremities, functional leg length disparity, and pelvic obliquity. Pelvic tilt, imposed by limb length inequality, can result in bilateral, unequal stresses on the hip and knee joints during an upright posture. Specifically, a tilted pelvis shifts the center of gravity's line of action away from the hip joint center on the side with the longer limb, necessitating increased muscle activity to compensate for this shift, potentially augmenting internal joint forces. Furthermore, pelvic tilt can disrupt the normal skeletal alignment, thereby reducing the contacting area of articulating joint surfaces. Increased pelvic obliquity resulting from excessive foot pronation can lead to lateral deviation and functional scoliosis of the lumbar spine. When there is unilateral leg shortening and excessive medial rotation of the limb, it can give rise to anterior pelvic tilt and increased lumbar lordosis. Lumbar scoliosis stemming from limb length shortening imposes asymmetric loads on intervertebral discs, contributing to their degeneration. These structural imbalances induced by unilateral foot pronation may be a causative factor for low back pain in certain individuals. The phenomenon of pelvic tilting plays a pivotal role in maintaining the center of gravity within the base of support, and deviations from ideal alignment can lead to compensatory postural strategies until the center of gravity returns to a stable position. Therefore, it is plausible that changes in foot alignment can result in postural alterations, spinal instability, balance disturbances, and structural abnormalities in accordance with the interconnected components of the human body [10, 11, 12, 13, 16, 17]

Comparative Changes Between Navicular Height in All Three Testing Positions:

A comparison of the alterations in Navicular height across all three testing positions was conducted using the ANOVA test, yielding a statistically significant result ($p = 0.0107$). This outcome signifies that the medial wedging employed in this study led to significant changes in the foot, as evidenced by the decrease in Navicular height across all three testing positions. Specifically, when foot hyperpronation was induced, it generated an adduction torque that forced the talus into adduction and plantar flexion, resulting in the downward shift of the navicular and eversion of the calcaneus. These findings align with previous research [5, 10, 11] that has emphasized the influence of subtalar movement and position on foot and lower limb biomechanical alignment. Pronation of the subtalar joint has been correlated with internal rotation of the shank. The unilateral or asymmetric presence of excessive calcaneal eversion is expected to induce a functional difference in lower extremity length and, consequently, may contribute to pelvic tilt toward the side exhibiting heightened foot pronation, potentially leading to a degree of scoliosis [11].

Comparative Changes Between Lumbar Spinal Alignment in All Three Testing Positions:

The statistical analysis of Lumbar spinal deviation, conducted using the ANOVA test, yielded a significant result (p-value 0.0505) across all three testing positions. It has been established that unilateral foot pronation can gradually induce kinematic changes culminating in functional scoliosis through the development of Limb Length Discrepancy. Even a minor discrepancy can result in pelvic obliquity in the frontal plane, which subsequently leads to scoliosis in the lumbar region. This phenomenon has been substantiated in previous research [2, 3, 12]. Additionally, it is well-documented that low back pain is associated with abnormal foot conditions. The biomechanical impact of muscles along the kinematic chain has been elaborated upon by various authors, including Thomas W. Myers, who has proposed the concept of muscle chains within the body. Among these chains, two are particularly relevant: the Superficial Back Line and the Lateral Line. The Superficial Back Line encompasses muscles such as the plantar fascia, triceps surae, ischiocrural muscles, sacrotuberal ligament, and erector spinae. The Lateral Line connects the sole of the foot and peroneal muscles, the iliotibial tract, tensor fasciae latae (TFL), gluteus maximus, obliques, quadratus lumborum muscles, intercostal muscles, splenius, and sternocleidomastoid (SCM) [1].

The process of induced foot pronation leads to the lowering of the navicular and medial arch, which subsequently tautens the plantar fascia. Eversion of the foot results in the stretching of the peroneal muscles, causing medial rotation of the tibia. This medial tibial rotation, in turn, stretches the iliotibial (IT) band and leads to internal rotation of the femur. The ipsilateral gluteus maximus contributes to the tilting of the pelvis, while contralateral quadratus lumborum is activated to shift the spine toward the opposite side in order to maintain the center of gravity. The most crucial aspect of lumbar biomechanics pertains to the translation that occurs during flexion and extension. The measurement of translation within the lumbar spine is pivotal in diagnosing spinal instability, with 2 mm of translation typically considered normal. The lumbar spine exhibits unique coupling patterns, and minimal mobility is observed in the transverse plane, which may directly or indirectly contribute to a higher incidence of clinical instability at the L4-L5 segment. Studies have also identified differences in coupling patterns between the upper lumbar segments (L1-L2, L2-L3, and L3-L4) and the lower lumbar segments (L4-L5 and L5-S1), with the upper lumbar spine displaying sidebend and rotation in opposite directions, while the lower lumbar segments exhibit sidebend and rotation in the same direction. The biomechanical and kinetic aspects of the lumbar spine continue to be areas of ongoing research and investigation, and the clinical implications of these findings warrant further exploration. The inclusion of both male and female subjects in this study aimed to eliminate potential gender-related discrepancies and ensure unbiased results. The chosen age group of 18-25 years was deliberate, as adolescence is a period characterized by maturation, accelerated growth, and individually variable changes in height, weight, and spinal dimensions. The dynamic nature of the spine, involving both bony and soft tissue elements, leads to changes that occur throughout this developmental phase. Thus, this study was designed to discern the impact of induced unilateral foot pronation on the lumbar spine in the frontal plane, with the objective of predicting subtle changes such as functional scoliosis and leg length disparities that may manifest at later stages and mitigating the long-term effects of abnormal posture [1, 2, 3, 5, 10, 11, 12, 13, 15, 16, 17].

Conclusion:

In summary, this investigation has elucidated a statistically insignificant correlation between Navicular height and Spinal Deviation in response to induced foot pronation. However, a significant and comparative outcome was discerned in the changes associated with Navicular height and Spinal deviation. The study underscores the intricate biomechanical relationships within the human body, particularly in the context of foot alignment and its potential implications for spinal alignment and stability. While the immediate changes induced by the foot manipulation in this study were transient, it is essential to acknowledge that individuals with prolonged foot pathologies may undergo postural adaptations over time to accommodate these deformities. The extensive body of research highlighting the influence of foot conditions on the pelvis and lumbar spine underscores the need for further investigation into the prevention and treatment of low back pain, considering the intricate interplay between these bodily components. Moreover, the study contributes to the broader understanding of how induced foot pronation can affect spinal alignment, leading to functional scoliosis, leg length discrepancies, and potential implications for long-term health and posture. Ultimately, this research serves as a valuable foundation for future studies aimed at exploring these complex biomechanical relationships and their clinical relevance.

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