ORIGINAL RESEARCH PAPER Volume - 15 | Issue - 08 | August - 2026 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

INFLUENCE OF FEMUR LENGTH ON TRUNK LEAN ANGLE DURING SQUAT: A BIOMECHANICAL ANALYSIS

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ABSTRACT

Excessive Trunk Lean angle while performing a squat is known to create biomechanical trade-offs such as increased recruitment of the posterior chain, reducing patellofemoral compression whilst simultaneously escalating anterior shear forces acting on the L5- S1 vertebral segment. This leads to increased risk of lumbar injuries. Prior research has indicated that anthropometric factors, such as femoral-shank length ratios, reduce individuals' ability to deep squat. Additionally, other studies stated that enhanced ankle dorsiflexion range of motion is an additional factor that affects trunk orientation during squat. However, research examining both these factors simultaneously is limited. Accordingly, this study aims to examine the influence of varying femur lengths and ankle dorsiflexion range of motion on trunk lean angle during the squat exercise. 30 Male Subjects performed a bodyweight squat descending to the deepest position possible while maintaining heel contact. Stance taken equivalent to the bi-acromial width of the participant, with toes pointing forward, the squats were performed barefoot to avoid any influence of shoes on foot elevation. Data analysis revealed that lower extremity mobility and flexibility, rather than absolute or relative anthropometric measures, were the primary determinants of compensatory trunk lean angle during the bodyweight squat. Restrictions in ankle dorsiflexion and knee flexion were strongly predictive of excessive trunk lean. These findings suggest that clinicians and strength coaches should prioritize screening ankle dorsiflexion range of motion and implement targeted ankle- and knee-focused mobility interventions to mitigate excessive trunk shear and promote upright squat posture.

KEYWORDS

Bodyweight-squat, Trunk lean angle, Femur Length, Ankle dorsiflexion.

INTRODUCTION

The squat represents a fundamental biomechanical pattern integral to executing numerous activities of daily living, such as toileting and chair transfers, as well as a diverse array of athletic endeavours. Consequently, the squat exercise is frequently employed within rehabilitation protocols and sport performance training regimens to elicit strength adaptations in the principal musculature of the lower extremities, notably the hip and knee extensors. (Anthony Caterisano, 2002) A growing body of evidence identifies the back squat as a keystone exercise for athletic development. Fundamentally, the squat movement pattern constitutes a primal biomechanical scaffold for sports specific force generation and coordinated movement, underpinning tasks such as jumping, sprinting, and change-of-direction manoeuvres(Gregory D Myer, 2015)

Proper technique while performing a squat is of critical importance. Furthermore, maintaining an upright trunk with a neutral lumbar curve during squats minimises anterior shear and compressive loads on the spine while maximising intra abdominal pressure for core stability, thereby safeguarding intervertebral discs and facet joints (Gregory D Myer, 2015) This posture also centres the load over the base of support, balances quadriceps and gluteal activation for optimal knee- and hip-extension moments, enhances neuromuscular control, and ensures superior transfer of strength gains to sport-specific movements with reduced injury risk(Victor Bengtsson, 2023). Trunk lean angle, defined as the inclination of the torso relative to the vertical plane, acts as a primary kinematic determinant for distributing mechanical load between the lumbar spine and the lower extremity joints (McKean, 2012) In particular the trunk lean angle while performing a squat critically modulates the external hip and knee flexion moments, with forward lean increasing hipextensor demand and reducing knee extensor loading(Rachel K Straub, 2024)

Consequently, the magnitude of this inclination creates a biomechanical trade-off; while increased forward lean recruits the posterior chain (Powers, 2003) and reduces patellofemoral compression(R F Escamilla, 2001) it simultaneously escalates anterior shear forces acting on the L5-S1 vertebral segment (Comfort, 2007) According to (Schoenfeld, 2010), generally a forward lean of 30-45 degrees relative to vertical is considered acceptable for a standard back squat. However, while some degree of forward inclination is 2 dictated by anthropometrics, safe trunk lean is generally characterised by maintaining a torso angle that is roughly parallel to the angle of the tibia. Deviations beyond this parallel relationship significantly increase the risk of lumbar injury due to excessive shear stress

Furthermore, it has been noted that a large thigh/shank length ratio, or a small trunk/thigh length ratio, may make a deep squat more difficult, due to the increased ankle dorsiflexion required. (ERIC DEMERS, 2018) Therefore, the increased biomechanical challenge associated with squatting may reduce the ability of individuals with certain anthropometric characteristics to perform this exercise effectively. Prior research has indicated that a higher thigh-to-shank length ratio is linked to greater knee flexion and ankle dorsiflexion angles during movement. Increased hip flexion could also be used to compensate. However, an increase in hip flexion does not exhibit a positive correlation as a compensatory mechanism (ERIC DEMERS, 2018).

Alternatively, (Contreras, 2016) reported that enhanced ankle dorsiflexion mobility, in combination with relatively shorter femoral length and a longer torso, contributes to a more vertical trunk orientation during squat performance. Accordingly, this study aims to examine the influence of varying femur lengths and ankle dorsiflexion range of motion on trunk lean angle during the squat exercise, intending to gain deeper insight into the compensatory strategies employed by individuals possessing relatively longer femurs. Therefore, a comprehensive analysis of the relationship between femoral length and sagittal trunk lean angle is needed for the individualized identification of movement limitations and asymmetries during squatting.

Considering previous studies, it was hypothesized that there will be a statistically significant correlation between absolute femur length and the forward trunk lean angle while performing the bodyweight squat. Alternatively, higher ankle dorsiflexion range would lead to a decreased forward trunk lean angle, hence resulting in a more upright squatting posture.

METHODS

To investigate how Femur Length and Ankle Dorsiflexion, Influences Trunk lean Angle during squat subjects performed controlled eccentric bodyweight squats to the maximum depth in a normal stance. Anatomical markers were placed on the essential landmarks and joint Angles were analyzed using the free software Kinovea. Moreover, all dependent variables were recorded at maximum values during the eccentric phase.

SUBJECTS

Thirty male University players from different team sports of LNIPE University, aged 18–25 years, were recruited via random sampling. With no reported history of lower-limb or spinal injuries in the preceding 12 months. Written consent was obtained from all the subjects before their involvement in the study

PROCEDURES

All trials were performed barefoot to eliminate the mechanical assistance provided by heel elevation in modern athletic footwear, thereby ensuring that observed ankle dorsiflexion and trunk lean were determined solely by each participant's biological range of motion and anthropometric characteristics. Participants adopted a standardized stance width equivalent to their individual bi-acromial (shoulder) width, and foot rotation was controlled by instructing participants to maintain their toes pointing directly forward to avoid the effective shortening of the femoral lever arm associated with hip abduction or external rotation. Each participant was instructed to descend to the deepest position possible while maintaining heel contact with the ground, as early heel rise would otherwise serve as a compensation for limited dorsiflexion. The eccentric phase of the squat was standardized to a 3-second duration to minimize reliance on the stretch-shortening cycle, and a rest interval of 30 seconds was provided between repetitions to prevent fatigue from influencing kinematic patterns.

Figure 1: Trunk Lean Angle

Furthermore, the ankle dorsiflexion range of motion for subjects was measured using a weight-bearing lunge test (WBLT). The test involved the participant lunging forward to maximize the inclination of the tibia relative to the foot while maintaining heel contact with the supporting surface. 3 trials for both feet were recorded, and the average of the best result for both feet was recorded for analysis.

Video recordings were obtained using standard procedures for 2-D video analysis(CARL J. PAYTON, 2007); under expert supervision.

Figure 2: Weight-bearing Lunge Test (wblt)

Angular kinematic variables were determined using Kinovea Video annotation tool, with a single camera positioned at a distance of 4 m from the subject and a height of 1.30 m; the Canon EOS 70D camera was used and set to record at 50 frames per second. Participants performed a bodyweight squat to their deepest possible depth while maintaining heel contact, using a stance width equal to their bi-acromial width, toes pointing forward, and barefoot to eliminate the influence of footwear on foot elevation; the squats were executed with a controlled 3-second eccentric phase and a 30-second rest interval between repetitions when required for analysis. Reflective markers were placed by an expert over key bony landmarks, including the acromion process, greater trochanter, lateral epicondyle of the femur, and lateral malleolus, and each participant wore tights of contrasting colour to enhance marker visibility and minimize artefacts due to clothing drift

DATA PROCESSING

Videographic analysis evaluated selected anthropometric and kinematic variables. Each participant performed three trials, from which the trial demonstrating the deepest position with maintained heel contact was selected for analysis. All measurements were conducted using Kinovea software, employing the angle tool to determine joint angles to the nearest degree. The joint angles reported in this study were peak trunk lean, knee flexion, and ankle dorsiflexion angles.

STATISTICAL ANALYSES

In order to examine the hypotheses of the study, Spearman Rank Correlation tests were used for evaluating the bivariate relationships between femur length, shank length, trunk length, thigh-to-shank ratio, trunk-to-thigh ratio, ankle dorsiflexion (WBLT average), knee flexion, and trunk lean angle. Normality was tested using the Shapiro-Wilk test. The data was analysed using IBM SPSS (version 27.0.1) with level of significance set at $\alpha = 0.05$.

Table – 1 : Descriptive Statistics

Variable	Mean	SD	Min	Max
Femur Length (cm)	42.13	3.27	37.0	47.0
Shank Length (cm)	44.00	2.86	38.0	49.0
Trunk Length (cm)	55.40	4.24	47.0	65.0
Femur-to-Shank Ratio	0.96	0.07	0.84	1.13
Femur-to-Trunk Ratio	0.76	0.07	0.65	0.94
Trunk Lean Angle (°)	25.97	10.1	14.0	58.0
WBLT Average (cm)	14.03	3.92	6.00	23.0
Knee Flexion (°)	137.40	11.3	92.0	157.
Ankle Dorsiflexion (°)	24.87	6.62	15.0	37.0

Table-1 Indicates substantial variability in anthropometric and kinematic measures among participants. Femur length (M = 42.13 ± 3.27 cm) and shank length (M = 44.00 ± 2.86 cm) showed moderate dispersion, while trunk length displayed a wider range (M = 55.40 ± 4.24 cm; 47–65 cm). The femur-to-shank ratio (M = 0.96 ± 0.07) and femur-to-trunk ratio (M = 0.76 ± 0.07) demonstrated relatively low variability, reflecting consistent segmental proportions across individuals. Kinematic variables showed greater spread, with trunk lean angle ranging from 14° to 58° (M = 25.97 ± 10.11°) and knee flexion ranging from 92° to 157° (M = 137.40 ± 11.35°). Ankle mobility measures indicated moderate dorsiflexion capacity, with WBLT scores averaging 14.03 ± 3.92 cm and ankle dorsiflexion angles averaging 24.87 ± 6.62°. Collectively, the data illustrate considerable inter-individual differences in both limb proportions and squat-related joint kinematics.

Table – 2: Shapiro-wilk Test

Variable	Statistics	p-value
Femur Length (cm)	0.9126	0.0199
Shank Length (cm)	0.9728	0.6366
Trunk Length (cm)	0.9859	0.9557
WBLT Avg (cm)	0.9834	0.9151
Trunk Lean Angle (°)	0.8862	0.0046
Knee Flexion (°)	0.8108	0.0001
Ankle Dorsiflexion (°)	0.9471	0.1542

Table – 3:spearman Rank Correlation With Trunk Lean Angle

Variable	ρ	Sig.
Femur Length	0.158	0.403
Shank Length	0.080	0.674
Trunk Length	-0.113	0.553
Femur/Shank	0.072	0.704
Femur/Trunk	0.140	0.460
WBLT Average	**-0.550**	**0.002**
Knee Flexion	**-0.506**	**0.004**
Ankle Dorsiflexion	**-0.475**	**0.008**

The findings imply that mobility and flexibility variables are the primary determinants of trunk lean angle, whereas segment lengths and anthropometric ratios have negligible influence when examined individually.

The Weight Bearing Lunge Test average ($\rho = -0.550$, $p = 0.002$), knee flexion ($\rho = -0.506$, $p = 0.004$), and ankle dorsiflexion ($\rho = -0.475$, $p = 0.008$) all show statistically significant moderate negative correlations with trunk lean angle, confirming that greater mobility is associated with reduced compensatory forward trunk lean.

In contrast, all assessed segment lengths (femur, shank, trunk) and anthropometric ratios (Femur/Shank, Femur/Trunk) demonstrated no significant relationships with trunk lean angle (ρ range 0.072 to 0.158, $p > 0.400$), indicating that their bivariate associations are too weak to serve as meaningful predictors of trunk posture.

CONCLUSIONS

The hypothesis for Mobility variables was accepted, as these variables demonstrated consistent and meaningful effects. All three mobility measures showed significant negative correlations with trunk lean angle. The Weight Bearing Lunge Test (WBLT Average) had the strongest association ($r = -0.550$, $p = 0.002$), indicating that greater ankle mobility resulted in a more upright trunk position. This was supported by Knee Flexion ($r = -0.506$, $p = 0.004$) and Static Ankle Dorsiflexion ($r = -0.475$, $p = 0.008$), which showed similar relationships. These findings align with the kinetic chain model, where restricted ankle motion shifts the centre of mass forward and increases the need for forward trunk lean to maintain balance. This is consistent with (Macrum, 2012), who reported increased trunk lean when ankle dorsiflexion was experimentally restricted, although their study used artificial conditions rather than natural squat patterns.

In contrast, anthropometric measures did not support the hypotheses proposing structural influence. Absolute segment lengths (femur, shank, trunk) and the derived ratios (Femur/Shank and Femur/Trunk) showed negligible and non-significant correlations with trunk lean angle (maximum $r = 0.158$, $p > 0.400$). These results indicate that limb proportions were not meaningful predictors of trunk posture in this sample. This finding aligns with (Fuglsang, 2017), who reported that anthropometric segment ratios were not statistically significant predictors of trunk lean. Instead, dynamic factors such as ankle dorsiflexion range of motion may play a more critical role in modulating barbell back squat kinematics. Overall, the results emphasize that available range of motion (Weight bearing lunge Test, Ankle Dorsiflexion, Knee Flexion) rather than skeletal structure (femur, shank, trunk, Femur/Shank and Femur/Trunk) is the key factor influencing trunk lean angle.

Based on the findings, it is concluded that lower extremity mobility and flexibility, rather than absolute or relative anthropometric dimensions, served as the primary determinants of sagittal trunk inclination during the bodyweight squat. Statistical analysis confirmed that while femur length and segmental ratios exhibited no significant influence on movement mechanics, restrictions in ankle dorsiflexion and knee flexion were strongly predictive of excessive trunk lean. These findings established that the inability to translate the tibia forward due to distal joint constraints necessitated a compensatory forward shift of the trunk to preserve the centre of mass, thereby validating the kinetic chain model over anthropometric structuralism as the driver of squat posture.

Recommendations for Future research include replicating this protocol with female participants to account for gender-specific differences in pelvic structure, Q-angle, and limb proportions. Furthermore, Longitudinal studies are recommended to determine the impact of specific mobility interventions (e.g., a 6-week dorsiflexion stretching protocol) that directly result in reduced trunk lean angle over time.

PRACTICALAPPLICATIONS

To encapsulate, clinicians and strength coaches are recommended to prioritize screening ankle dorsiflexion range of motion and implement targeted ankle- and knee-focused mobility interventions to mitigate excessive trunk lean and promote upright squat posture.

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