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Original Research Article

Squat mechanics as predictors of countermovement jump performance in healthy young adults: a cross-sectional study

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ABSTRACT

Background: Squat depth and dynamic knee valgus (DKV) are widely discussed determinants of lower-limb performance and injury risk, yet their independent contribution to jump performance has rarely been examined together, particularly using accessible, application-based tools. This study examined whether squat depth and DKV predict countermovement jump (CMJ) performance in healthy young adults.
Methods: In this cross-sectional study, 139 healthy young adults (71 men, 68 women; 18-25 years) underwent smartphone/tablet-based biomechanical assessment. Squat depth was quantified as trochanteric displacement normalised to femur length during a self-selected bodyweight squat; DKV was measured from frontal-plane video as peak medial knee displacement; CMJ, squat jump and horizontal jump performance were assessed using a validated flight-time application. Associations were examined using Spearman correlation, multiple linear regression (adjusted for age, sex and body mass index [BMI]), and squat-depth quartile comparison.
Results: Squat depth correlated strongly with CMJ height (r=0.72), squat jump height (r=0.76) and horizontal jump length (r=0.61, all p<0.001), and remained an independent predictor of CMJ height after adjustment (β=6.79 cm per unit depth, p<0.001; model R^2=0.879). DKV was not associated with squat depth (r=-0.12, p=0.152) and showed only a borderline association with CMJ height (β=-0.383, p=0.051). A squat-depth×sex interaction on DKV approached but did not reach significance (β=1.44, p=0.078).
Conclusions: Squat depth, not DKV, was a strong, independent predictor of CMJ performance. Squat depth showed no meaningful relationship with knee valgus, suggesting the two are largely independent expressions of lower-limb function in healthy young adults.

Keywords: Squat depth, Knee valgus, Countermovement jump, Vertical jump performance, Biomechanics, Lower limb

INTRODUCTION

The lower limb behaves as an integrated kinetic chain during almost every athletic and everyday task, and the coordination of hip, knee and ankle motion during closed-chain movements strongly influences both performance and musculoskeletal injury risk.[1] The squat is often described as the "king of exercises" because it is a compound, multi-joint movement that recruits the quadriceps, hamstrings, gluteal and calf musculature while simultaneously demanding trunk stabilisation.[2,3] Deviations from neutral frontal-plane alignment during the squat-particularly dynamic knee valgus (DKV), the medial collapse of the knee relative to the hip and ankle-have been consistently associated with elevated anterior cruciate ligament (ACL) strain and patellofemoral joint stress.[1,4]

Squat depth is among the most debated technical parameters of the exercise. Deeper squats recruit greater gluteal and quadriceps activity but also raise patellofemoral and tibiofemoral joint loading, and have been theorised to amplify frontal-plane knee collapse, particularly when ankle dorsiflexion or hip motor control is limited.[2,5] Experimentally restricting ankle dorsiflexion range has been shown to simultaneously reduce achievable squat depth and increase knee valgus and medial knee displacement, while patients with patellar tendinopathy squat to significantly less depth and show greater valgus than asymptomatic controls, hinting at an inverse rather than a direct depth-valgus relationship.[2,6] Conversely, vertical jump performance-commonly assessed through the CMJ, squat jump (SJ) and horizontal jump (HJ)-is a well-established, field-friendly index of lower-limb explosive power that shares a biomechanical basis with the squat, since both rely on coordinated triple extension of the hip, knee and ankle and, in the case of the CMJ, on the stretch-shortening cycle generated through an eccentric amortisation phase functionally similar to a squat descent.[7,8]

Although squat depth, DKV and jump performance have each attracted substantial research attention, they have rarely been examined together within a single analytical framework, and much of the available evidence derives from laboratory-based three-dimensional motion capture in athletic, clinical, or Western populations.[9-11] Portable, application-based tools capable of quantifying jump height, segmental displacement and frontal-plane alignment outside a dedicated biomechanics laboratory have been validated with varying success against three-dimensional reference standards, and their combined, integrated use-together with normative data from young Indian adults-remains scarce.[12-16]

We therefore conducted this cross-sectional study to examine, within a single analytical framework, the relationship between squat depth, DKV and vertical jump performance in healthy young adults, using accessible smartphone- and tablet-based biomechanical assessment tools. The primary objective was to determine whether squat depth and DKV independently predict CMJ performance. The secondary objectives were to examine the relationship between squat depth and DKV itself, to test whether this relationship is modified by sex, and to characterise how squat depth and knee valgus each vary with jump performance after accounting for age, sex and BMI.

METHODS

Study design and setting

This cross-sectional analytical study was conducted from September 2025 to June 2026 in a dedicated biomechanical assessment room at the department of anatomy, Subharti Medical College, Meerut, Uttar Pradesh, India. The assessment room had standardised flooring, lighting and camera set-up. Ethical approval was obtained from the Institutional Ethics Committee of SVSU prior to recruitment, and the study was conducted in accordance with the Declaration of Helsinki.

Participants

Healthy adults aged 18-25 years from the student population were eligible if they could perform an unloaded bodyweight squat and a vertical jump without pain or apprehension and had no musculoskeletal, neurological or cardiorespiratory condition likely to limit either task; individuals with a current or recent (within six months) lower-limb injury or surgery, a balance-affecting neurological or vestibular condition, pregnancy, or prior personal use of the assessment applications were excluded. A quota-based approach was used to maintain a broadly balanced sex distribution. Written informed consent was obtained from all participants via a paper information sheet supplemented by a digital e-consent form.

The sample size was calculated for detecting a correlation of $r=0.30$ between squat depth and DKV (two-sided $\alpha=0.05$, 90% power), requiring approximately 113 participants; allowing for an estimated 10% unusable recordings, recruitment targeted approximately 120 participants (minimum 40 per sex). A total of 139 participants (71 men, 68 women) were ultimately enrolled and analysed.

Instrumentation and procedures

Three tablet/smartphone-based applications (MyJump Lab, Carlos Balsalobre) formed the measurement toolkit. All video recordings were captured at a minimum of 60 frames per second on a fixed tripod positioned perpendicular to the plane of motion.

Squat depth was derived from sagittal-plane video (MyROM module) rather than the application’s built-in knee-flexion-angle output, because piloting showed the latter to be sensitive to trunk lean and camera angle during a compound, multi-joint squat. Instead, the vertical pixel displacement of the greater trochanter between the upright starting position and the lowest point of a self-selected bodyweight squat was measured frame-by-frame and normalised to femur length (greater trochanter to lateral femoral epicondyle) measured on the same still frame, giving a dimensionless squat-depth ratio independent of absolute image scale. Three trials were averaged per participant.

DKV was assessed with a marker-less, frontal-plane video-tracking application (MyMocap) during the same bodyweight squat used for the depth measurement, so that both variables derived from a single movement. The application estimated peak medial knee displacement, in degrees, relative to a hip-ankle reference line, across three trials per limb. Where a trial failed to register a value, a pre-specified reduction rule (averaging the remaining valid trials, or carrying forward a single valid trial) was applied;

the higher of the two limb-specific scores was taken as each participant's overall knee valgus value.

Jump performance was assessed with the MyJump application using a validated flight-time algorithm. The CMJ (hands on hips, permitting a self-paced countermovement) and SJ (static semi-squat start, no countermovement) were each performed for three trials, with the best trial retained as the primary outcome (height in cm; force, power and related kinetic variables calculated by the application); a horizontal (standing broad) jump distance was also recorded. Standing height, body weight, BMI, body fat percentage and skeletal muscle mass were measured with a stadiometer and a bioelectrical impedance analyser; leg length was taken from the same standardised video frame used for the squat-depth calculation.

Statistical analysis

Continuous variables were screened for normality using the Shapiro-Wilk test; because squat depth, knee valgus and all three jump metrics departed from normality, Spearman's rank correlation was used as the primary measure of association, with Pearson's r reported for comparison. Male-female comparisons used the Mann-Whitney U test (Wilcoxon signed-rank test for paired left/right comparisons), with Cohen's d reported as an effect size. Multiple linear regression was used to model (i) CMJ height as a function of squat depth, knee valgus, BMI, age and sex, and (ii) knee valgus as a function of squat depth, BMI, body fat percentage, muscle mass, age and sex; a squat-depth×sex interaction term was added to a simplified model of the latter to test effect modification. Variance inflation factors were examined for multicollinearity. Participants were also divided into squat-depth quartiles and compared using the Kruskal-Wallis test. Trial-to-trial reliability of knee valgus was assessed using the intraclass correlation coefficient (two-way, single-measures, consistency; ICC(C,1)), interpreted using conventional benchmarks.[17] A two-sided $p<0.05$ denoted statistical significance throughout; analyses were performed in Python (pandas, SciPy, statsmodels, pingouin).

RESULTS

Participant characteristics

A total of 139 participants (71 men, 68 women) were analysed. Mean age was 18.25±1.47 years and did not differ by sex (p=0.137). Height, body weight and leg length were significantly greater in men (all p<0.001), whereas BMI did not differ meaningfully between sexes (23.11±3.16 vs 23.62±4.86 kg/m², p=0.899) (Table 1).

Squat depth, knee valgus and jump performance

Normalised squat depth averaged 1.165±0.281 femur-lengths overall and was significantly greater in men (1.312±0.243) than women (1.012±0.232, p<0.001, Cohen's d=1.26), ranging from 0.591 to 1.801 femur-lengths across individuals (Figure 1). Knee valgus showed a negligible sex difference (men 3.24±1.30°, women 3.35±0.92°, p=0.151, d=-0.10). All three jump metrics were markedly higher in men than women (Cohen's d 3.33-4.47): CMJ height 28.37±3.61 vs 15.53±2.66 cm; SJ height 26.29±3.90 vs 15.01±2.74 cm; HJ length 161.09±14.47 vs 103.00±11.24 cm (all p<0.001) (Table 2). Trial-to-trial reliability of knee valgus was poor-to-moderate (ICC(C,1) 0.246 left, 0.255 right limb; mean within-subject coefficient of variation 55.5-63.7%).

Squat depth and jump performance

Squat depth correlated strongly and positively with CMJ height (r=0.72), SJ height (r=0.76) and HJ length (r=0.61, all p<0.001), moderately with leg length (r=0.49), and inversely with BMI (r=-0.28) (Table 3). In multiple regression, squat depth remained an independent, significant predictor of CMJ height after adjustment for knee valgus, BMI, age and sex (β=6.79 cm per unit of normalised depth, p<0.001; standardised β=0.27), as did sex (β=10.67 cm, p<0.001, the dominant term in the model) and BMI (β=-0.17, p=0.002); knee valgus approached but did not reach conventional significance (β=-0.38, p=0.051), and age contributed nothing (p=0.992). The overall model explained a substantial proportion of variance in jump height (R^2=0.879, adjusted R^2=0.874, F(5,133)=192.4, p<0.001), with no evidence of problematic multicollinearity (maximum variance inflation factor 1.68) (Table 4 and Figure 2).

Relationship between squat depth and knee valgus

Squat depth was not significantly correlated with knee valgus in the whole cohort (Spearman r=-0.12, 95% CI -0.28 to 0.05, p=0.152; Pearson r=0.05, p=0.596) (Figure 3, Table 3). Sex-stratified correlations were similarly non-significant (men: r=0.02, p=0.847; women: r=-0.12, p=0.319), as was the partial correlation adjusting for sex (r=-0.07, p=0.441). In multiple regression with knee valgus as the outcome, none of squat depth, BMI, body fat percentage, muscle mass, age or sex reached significance, and the model explained negligible variance (R^2=0.027, adjusted R^2=-0.017, F(6,132)=0.61, p=0.722) (Table 5). A squat-depth×sex interaction term added to a simplified model approached but did not reach significance (β=1.44, SE=0.81, p=0.078).

Squat depth quartile comparison

Across squat-depth quartiles, CMJ height rose in an essentially monotonic, stepwise pattern from Q1 (15.86±4.03 cm) to Q4 (28.54±4.87 cm; Kruskal-Wallis H=66.2, p<0.001), with SJ height and HJ length showing the same pattern (H=74.1 and 52.1 respectively, both p<0.001); knee valgus, by contrast, did not differ meaningfully across quartiles (Kruskal-Wallis H=2.01, p=0.570; Q1 3.33±0.65° vs Q4 3.41±1.85°, p=0.205) (Table 6 and Figure 4).

Table 1: Participant characteristics by sex.

Variables	Male, (n=71)	Female, (n=68)	Overall, (n=139)	P
Age (in years)	18.43±1.59	18.06±1.32	18.25±1.47	0.137
Height (cm)	171.1±6.2	158.2±6.6	164.8±9.1	<0.001
Body weight (kg)	70.4±10.5	60.5±12.2	65.6±12.4	<0.001
BMI (kg/m²)	23.11±3.16	23.62±4.86	23.36±4.08	0.899
Leg length (cm)	89.6±4.8	82.5±4.8	86.1±6.0	<0.001

*Values are mean± SD. p values from Mann-Whitney U test.

Table 2: Sex differences in squat depth, knee valgus and jump-performance variables.

Variables	Male, (n=71)	Female, (n=68)	P	Cohen's D
Squat depth (femur-lengths)	1.312±0.243	1.012±0.232	<0.001	1.26
Knee valgus (deg)	3.236±1.304	3.352±0.916	0.151	-0.10
CMJ height (cm)	28.37±3.61	15.53±2.66	<0.001	4.04
SJ height (cm)	26.29±3.90	15.01±2.74	<0.001	3.33
HJ length (cm)	161.09±14.47	103.00±11.24	<0.001	4.47
BMI (kg/m²)	23.11±3.16	23.62±4.86	0.899	-0.13

*Values are mean±SD. p from Mann-Whitney U test. Cohen's d=standardised mean difference (male-female); interpreted as negligible (<0.2), small (0.2-0.5), medium (0.5-0.8) or large (≥0.8).

Table 3: Spearman correlation matrix of key study variables (r values; n=139).

Variables	Squat depth	Knee valgus	CMJ height	SJ height	HJ length	BMI	Leg length
Squat depth	1.00	-0.12	0.72	0.76	0.61	-0.28	0.49
Knee valgus	-0.12	1.00	-0.22	-0.18	-0.25	0.12	-0.12
CMJ height	0.72	-0.22	1.00	0.95	0.90	-0.19	0.68
SJ height	0.76	-0.18	0.95	1.00	0.89	-0.21	0.69
HJ length	0.61	-0.25	0.90	0.89	1.00	-0.09	0.61
BMI	-0.28	0.12	-0.19	-0.21	-0.09	1.00	-0.18
Leg length	0.49	-0.12	0.68	0.69	0.61	-0.18	1.00

*Spearman rank correlation coefficients. Correlations of |r|≥0.61 correspond to p<0.001; the squat depth-knee valgus correlation (r=-0.12) was not significant (p=0.152).

Table 4: Multiple linear regression predicting CMJ height (cm).

Predictors	B	SE	T	P
Intercept	14.094	3.126	4.51	<0.001
Squat depth	6.791	1.003	6.77	<0.001
Knee valgus	-0.383	0.194	-1.97	0.051
BMI	-0.174	0.056	-3.14	0.002
Age (in years)	-0.002	0.158	-0.01	0.992
Sex (male=1)	10.665	0.518	20.60	<0.001

*Model: R^2=0.879, adjusted R^2=0.874, F(5,133)=192.4, p<0.001. Maximum variance inflation factor=1.68 (no evidence of problematic multicollinearity).

Table 5: Multiple linear regression predicting knee valgus (degrees).

Predictors	B	SE	T	P
Intercept	3.114	2.536	1.23	0.222
Squat depth	0.412	0.468	0.88	0.381
BMI	-0.069	0.176	-0.39	0.697
Body fat %	0.058	0.111	0.52	0.605
Muscle mass (kg)	-0.014	0.023	-0.64	0.523
Age (in years)	0.070	0.072	0.97	0.332
Sex (male=1)	-0.163	0.280	-0.58	0.562

*Model: R^2=0.027, adjusted R^2=-0.017, F(6,132)=0.61, p=0.722. A squat depth × sex interaction term added to a simplified model approached but did not reach significance (β=1.437, SE=0.809, p=0.078).

Table 6: Knee valgus and jump performance across squat-depth quartiles, (mean±SD).

Quartile	Squat depth range (femur-lengths)	Knee valgus (deg)	CMJ height (cm)	SJ height (cm)	HJ length (cm)
Q1	0.591-0.941	3.33±0.65	15.86±4.03	14.98±3.60	106.39±20.02
Q2	0.941-1.113	3.21±0.76	19.30±5.86	17.86±4.79	122.53±25.35
Q3	1.119-1.390	3.21±0.87	24.72±6.18	22.91±5.32	146.28±28.63
Q4	1.395-1.801	3.41±1.85	28.54±4.87	27.41±4.42	155.87±27.07

*Kruskal-Wallis test across quartiles: knee valgus H=2.01, p=0.570; CMJ height H=66.2, p<0.001; SJ height H=74.1, p<0.001; HJ length H=52.1, p<0.001.

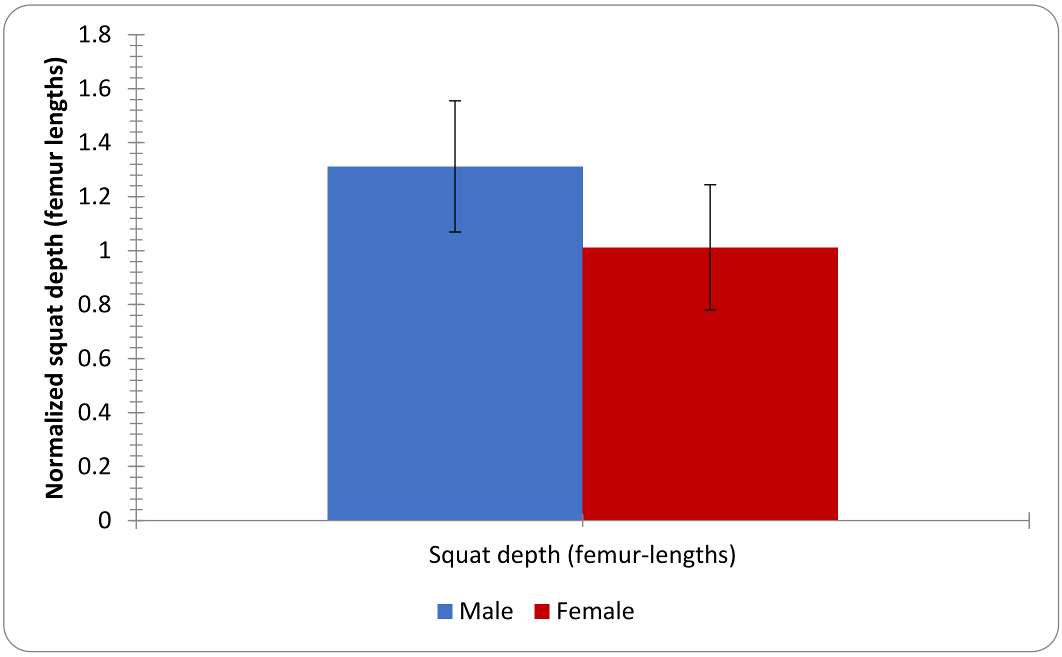

Figure 1: Normalised squat depth by sex.

*Normalised squat depth (femur-lengths) by sex, mean±SD. Male 1.312±0.243; female 1.012±0.232 (p<0.001, Cohen's d=1.26).

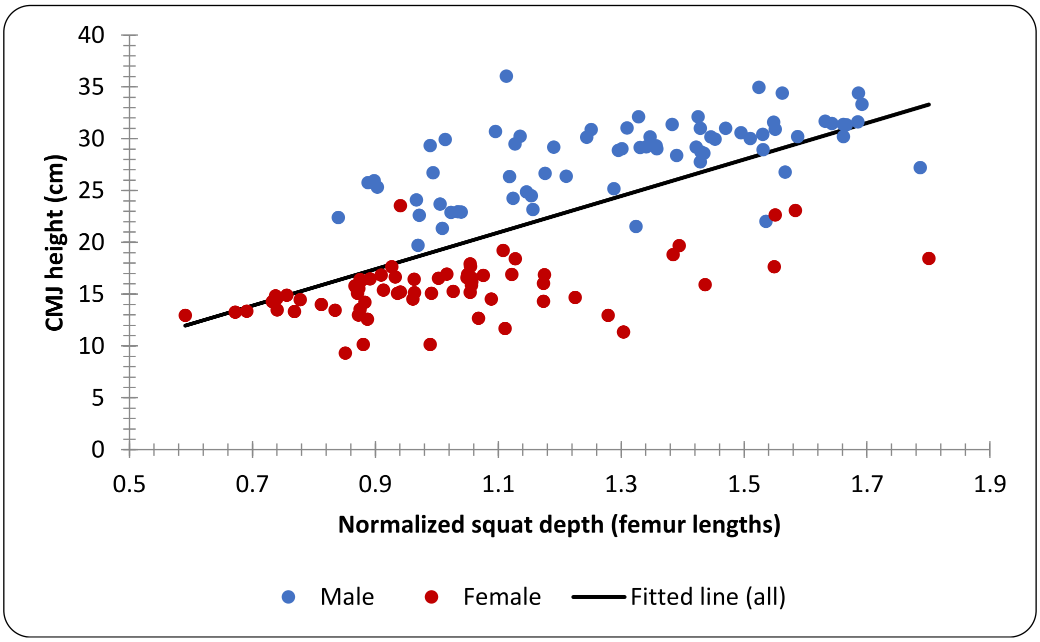

Figure 2: Relationship between squat depth and CMJ height.

*Relationship between normalised squat depth and CMJ height, by sex, with fitted linear trendline (pooled Pearson r=0.69; whole-sample Spearman r=0.72, p<0.001).

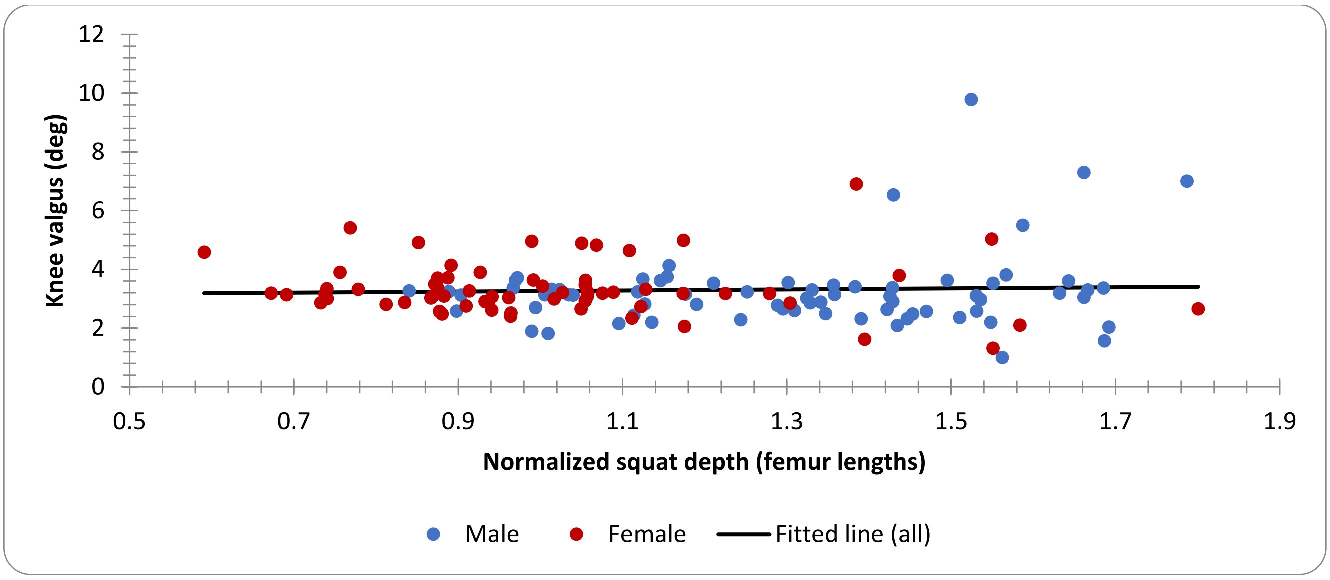

Figure 3: Relationship between squat depth and knee valgus.

*Relationship between normalised squat depth and knee valgus, by sex, with fitted linear trendline (pooled Pearson r=0.05, not significant; whole-sample Spearman r=-0.12, p=0.152).

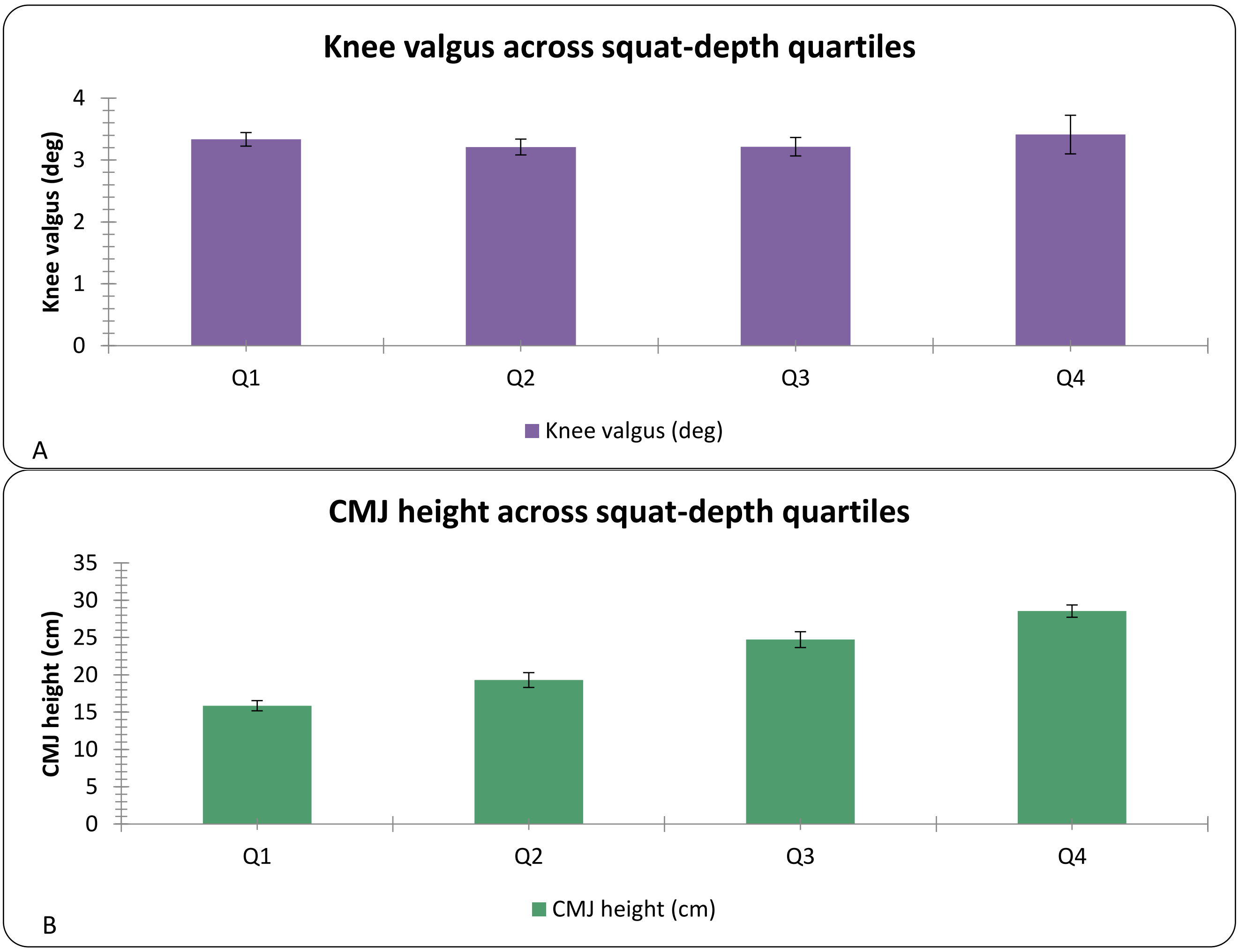

Figure 4 (A and B): Knee valgus and CMJ height across squat-depth quartiles.

*Knee valgus and CMJ height across squat-depth quartiles (Q1=shallowest to Q4=deepest; mean ± SEM). CMJ height increased monotonically across quartiles (Kruskal-Wallis H=66.2, p<0.001); knee valgus did not differ meaningfully, (H=2.01, p=0.570).

DISCUSSION

This cross-sectional study examined, within a single analytical framework, whether squat depth and DKV predict CMJ performance in 139 healthy young adults. Two clear and internally consistent findings emerged. First, squat depth was a strong and independent predictor of jump performance across correlation, multivariable regression and quartile-based analyses, holding up after adjustment for sex, age and BMI. Second, squat depth showed no meaningful relationship with DKV across four separate analytical approaches-overall and sex-stratified correlation, partial correlation, multivariable regression and quartile comparison-and knee valgus itself showed, at most, a borderline independent association with jump performance.

The absence of a squat-depth-to-valgus relationship runs counter to the common clinical assumption that deeper, more demanding squats bring participants closer to the limits of their frontal-plane control.[1,4] Where the literature has examined this relationship, the pattern is, if anything, in the opposite direction to what was originally hypothesised: patients with patellar tendinopathy squat less deep and show greater valgus than asymptomatic controls, and experimentally restricting ankle dorsiflexion simultaneously reduces achievable depth and increases valgus both consistent with the small negative correlation observed here, rather than a positive one.[2,6] A more consistent thread in the wider literature is that DKV is driven predominantly by proximal (hip) and distal (ankle) neuromuscular control rather than by sagittal-plane range of motion per se: reduced hip internal or external rotation range and restricted ankle dorsiflexion have each been linked to greater valgus during single-leg squatting and landing tasks, and core/lumbopelvic control measures relate more to hip frontal-plane angle than to knee projection angle itself. [10,11,18,19] If valgus is substantially a downstream product of hip and ankle control rather than of squat depth, a weak or absent direct correlation between depth and valgus is exactly what would be expected, and is consistent with what was observed in this cohort.

A methodological caveat is warranted: trial-to-trial reliability of the knee valgus measurement was poor-to-moderate (ICC(C,1)≈0.25), considerably lower than reliability figures reported for comparable two-dimensional or marker-less video methods elsewhere (ICC 0.65-0.98).[12,15,17,20] Unreliable measurement of an outcome variable systematically attenuates correlation coefficients toward zero, so the null squat-depth-valgus finding reported here should be read as "no relationship detectable with this measurement approach" rather than definitive proof of no relationship in the underlying biomechanics.

In contrast, the squat-depth-jump-performance relationship was strong and consistent, fitting comfortably within the broader strength-and-conditioning literature connecting squat-pattern range of motion to lower-limb power output.[7,8] Mechanistically, a deep squat and an effective CMJ share similar prerequisites-ankle dorsiflexion range, hip flexion range, and eccentric control through a long range of motion-so that a participant unable to access a comfortably deep squat is, almost by definition, also constrained in the countermovement depth available to exploit the stretch-shortening cycle during a jump. Seen this way, the relationship reported here largely confirms, using a low-cost field-based method, an association the training literature has generally assumed. The borderline squat-depth×sex interaction on knee valgus (p=0.078) is worth noting without over-interpretation: with approximately 70 participants per sex, this study was likely underpowered to confirm an interaction of this modest size, and the wider literature on sex differences in valgus is itself mixed, with some studies reporting negligible sex differences in medial knee displacement and others reporting significantly greater valgus in females a pattern consistent with the negligible sex effect on knee valgus magnitude observed here (Cohen's d=-0.10).[20,21]

This study has several strengths: sample size (139) exceeding priori target, near-balanced sex distribution enabling sex to be examined as both covariate and potential effect modifier, and convergent testing of the primary hypothesis through four independent analytical approaches. The use of low-cost, tablet-and smartphone-based tools rather than laboratory-grade 3D motion capture also reflects a broader, well-supported shift toward accessible biomechanical assessment, and made a sample of this size feasible within single research programme.[15,16]

Several limitations should be considered. The cross-sectional design permits association but not causal inference, and cannot distinguish whether deeper squatting mechanically contributes to jump performance, whether both reflect a shared strength/power phenotype, or whether both are influenced by shared training history. Participants were a convenience sample drawn from a single institution's medical, dental and physiotherapy student cohorts, which may limit generalisability to other populations. Hip and ankle range of motion and electromyographic data were not collected directly, so mechanistic hypotheses regarding proximal and distal control could only be discussed with reference to the wider literature rather than tested against this study's own data. Knee valgus was captured during a bilateral, self-paced bodyweight squat, a comparatively low-demand task relative to the single-leg squats, landings and cutting manoeuvres used in much of the comparison literature, and the modest trial-to-trial reliability of this measurement places a ceiling on how confidently a true absence of relationship can be asserted. No injury outcome data were collected, so this study cannot speak directly to injury risk, only to the biomechanical relationships commonly assumed to underlie it.

CONCLUSION

In conclusion, squat depth-not DKV-emerged as a strong, independent, sex- and BMI-adjusted predictor of CMJ performance in healthy young adults, a relationship that held up consistently across correlation, regression and quartile-based analyses. Squat depth showed no meaningful relationship with DKV in this cohort, suggesting that, at least as measured here, squat depth and DKV represent largely independent expressions of lower-limb function. These findings suggest that a simple, low-cost squat-depth assessment may have practical value for screening explosive lower-limb power in field and clinical settings, but should not be relied upon as a proxy for frontal-plane knee-control risk; future work using more reliable valgus measurement, longitudinal follow-up and direct hip/ankle range-of-motion data is needed to clarify what does drive DKV in this population.

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Ethical approval: The study was approved by the Institutional Ethics Committee

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